Late Holocene Pollen Stratigraphy in Four Northeastern United States Lakes

K. Gajewski, A. M. Swain et G. M. Peterson

Volume 41, numéro 3, 1987

URI : id.erudit.org/iderudit/032693ar
DOI : 10.7202/032693ar

Citer cet article

LATE HOLOCENE POLLEN STRATIGRAPHY IN FOUR NORTHEASTERN UNITED STATES LAKES


ABSTRACT Four pollen diagrams from Maine, New York, and Pennsylvania provide fine resolution (40 or 80 years) records of vegetation change in northeastern United States during the past 2000 years. A long term increase in pollen accumulation rates (PAR) of Picea occurred at the three sites in Maine and New York. Around 1100 years ago, Tsuga and Fagus decreased and Quercus and Castanea increased at Ely Lake in northeastern Pennsylvania. Around 500 years ago, Tsuga and Fagus greatly decreased in Maine and northern New York, while in northeastern Pennsylvania there was an increase in Tsuga and Fagus and a decrease in Quercus and Castanea pollen. Non-arboreal PAR were negligible prior to the European settlement of the area, after which there was an abrupt increase in non-arboreal pollen types.


* Present address: Division of Life Sciences, Scarborough College, 1265 Military Trail, Scarborough, Ontario M1C 1A4.
** Present address: 350 Kent Lane, #101, Madison, Wisconsin 53713, U.S.A.
INTRODUCTION

Late Holocene pollen diagrams from northeastern United States and southeastern Canada show an increase in *Picea* and other boreal forest pollen types and a decrease in *Tsuga* and hardwood types (BERNABO and WEBB, 1977; DAVIS, 1983; DAVIS et al., 1980; DAVIS et al., 1975; GAUDREAU and WEBB, 1985; LIKENS and DAVIS, 1975; MOTT, 1975, 1977; RICHARD, 1977). Between 2000 years BP and the present, the area of abundant *Tsuga* and *Fagus* pollen percentages decreased both in northern New England and southeastern Canada and in southern New England and northern Pennsylvania; this was the result of the increase in *Picea* in the north and at least partly due to anthropogenic activities to the south (GAUDREAU and WEBB, 1985). In southern New England, *Quercus* pollen decreased and *Castanea* first appeared in the pollen record in the past 2000 years (DAVIS, 1969; GAUDREAU and WEBB, 1985; WHITEHEAD, 1979). Few other large-scale patterns can be detected either from individual pollen diagrams or from mapped changes in pollen percentages (BERNABO and WEBB, 1977; GAUDREAU and WEBB, 1985).

Most pollen diagrams have little detail in the late Holocene and resolve only long term changes in vegetation formations. Dating of the sediment sequences is usually based on extrapolation from a few radiocarbon dates, which puts a limit on the temporal scale of events in the pollen record that can be correlated between sites. Sequences of maps showing the spatial patterns of pollen deposition at the beginning and end of this time period (e.g. GAUDREAU and WEBB, 1985) do not indicate the rates of vegetation changes. Four pollen records from lakes with varved sediments (Fig. 1) were obtained to show in detail the sequence of vegetation change in northeastern United States for the past 2000 years.

The overall pattern of vegetation in the study area (Fig. 1; BARRETT, 1980; LULL, 1968; WESTVELD, 1956) ranges from an area of predominantly spruce-fir forest type in the northeast to an area of oak-hickory forest type in the south. Between these northern and southern forest types is a broad zone consisting of northern hardwood and hemlock — white pine — northern hardwoods forest types.

At each coring site the vegetation varies in more detail than can be shown on Figure 1. In northern Maine (Conroy Lake) spruce-fir forest type (which includes *Picea glauca, P. rubens*, and *Abies balsamea*) is predominant, with northern hardwoods forest type (*Fagus grandifolia, Betula lutea*, and *Acer saccharum*) more abundant on mesic sites (OOSTING and REED, 1944). In southern Maine (Basin Pond), northern hardwoods are regionally important (Fig. 1), with *Pinus strobus* more abundant on coarser soils (BARRETT, 1980) or after disturbance. In northern New York (Clear Pond), spruce-fir forests are dominant at higher elevations in the Adirondack Mountains, while hemlock-hardwood forests increase in abundance to the south. In northeastern Pennsylvania (Ely Lake) the northern hardwoods are more important in more mesic sites, while *Quercus* becomes more abundant on drier sites (BARRETT, 1980). None of the lakes has bogs on the periphery.

METHODS

Sediment cores were collected from the deepest portion of each lake (by A. Swain and R. Steventon) using a 5 cm diameter freezing corer (SWAIN, 1973; WRIGHT, 1980). The sediment was stored frozen until analyzed and varves were counted on the frozen cores. The cores were marked off at ten year intervals and the width of the ten-year sections was measured using a catheterometer. Strips of the measured frozen sediment were removed to obtain subsamples for pollen analysis. Inspection of these strips showed minimal deformation of the laminations due to the penetration of the corer. For the cores from Ely Lake and Clear Pond, the sediment was placed in Carbowax and the hardened sediment was trimmed to a measured volume, after SWAIN (1978). For the cores from Basin Pond and Conroy Lake, the sediment was melted to room temperature and then was measured in a 0.5 ml calibrated spoon. The subsamples were all similarly processed using standard methods (FAEGRI and IVERSEN, 1975), including 10% KOH, 10% HCI, concentrated HF and acetylization solution. The stained residue was mounted in silicone oil. Eucalyptus tablets were added to the sediment prior to processing to enable the calculation of pollen concentration (see MAHER, 1981), and the measurements of the sediment thickness enabled the computation of pollen accumulation rates. A discussion of the confidence limits of the pollen accumulation rates derived using these methods can be found in GAJEWSKI et al., (1985). The pollen sum consists of at least 300 grains/level. Counts range between 300 and 480 grains, with an overall mean of approximately 350 grains/level.
RESULTS

In the remainder of this paper, reference to pollen amounts will indicate pollen accumulation rates (PAR; influx, pollen deposition rates) unless specifically stated otherwise. In all four pollen diagrams discussed in this paper, PAR is constant at roughly 10000 grains/cm²/yr (Gajewski, 1983), and thus the diagrams can be easily compared to percentage pollen diagrams.

CONROY LAKE

The Conroy Lake pollen accumulation rate diagram (Fig. 2) covers the past 1970 years. As described in Appendix I, a dating correction has been applied to the upper 150 years. All identified pollen grains are used to create the pollen diagram, although several rare types are aggregated in the categories “Other Trees and Shrubs” and “Other Herbs”. PAR of several of the uncommon taxa which are included on some, but not all, of the pollen diagrams are listed in Table I. Tables of all of the taxa included in these two categories, as well as tables of the pollen percentages are available from the authors.

Zone I (1970 to 500 years ago) was characterized by low, but increasing amounts of *Picea* pollen. *Pinus strobus* pollen varied between 500 and 2000 grains/cm²/yr with relative minima centered around 800 and 1300 years ago. *Tsuga* pollen was relatively abundant in this zone, except for the time around 1800 years ago, when the accumulation rate decreased to less than 500 grains/cm²/yr. Beginning around 900 years ago, *Tsuga* pollen steadily declined. *Betula* pollen increased slightly from 2000 to 1700 years ago, remained at high values until 1200 years ago and subsequently decreased between 1100 and 500 years ago. Other hardwoods, such as *Fagus*, *Acer*, *Ostrya/Carpinus*, *Ulmus*, *Quercus*, and *Fraxinus* were present in very low amounts, and showed no long-term changes.

In Zone II (500-150 years ago), *Picea* PAR rapidly increased. *P. strobus*, *Betula* and *Alnus* pollen increased slightly. *Tsuga* and *Cupressineae* pollen decreased in this zone; this decrease in *Tsuga* continued the trend begun 900 years ago. A low, but consistent influx of *P. banksiana/resinosa* pollen suggests long-distance transport. Maxima and minima in the PAR curves were registered in all pollen types simultaneously (e.g. 350 or 500 years ago) and thus reflect sedimentological rather then pollen-depositional events (see Swain, 1978).

In Zone III (150 years ago to A.D. 1974) non arboreal pollen (NAP) abruptly increased, as the landscape was disturbed by the activities of European settlement. *Alnus* increased and *Populus* pollen was consistently present for the first time in the past 2000 years. Pollen of several tree taxa increased, but the possibility of multiple annual laminations (see Appendix I) precludes detailed interpretation of these PAR values. *Tsuga* and *Fagus* pollen accumulation rates further decreased.

BASIN POND

The Basin Pond PAR diagram (Fig. 3), covering the past 1600 years prior to 1974, was also divided into three zones. Changes in this diagram are broadly similar to those of Conroy Lake, although the PAR of the various taxa can be quite different. *Tsuga*, *Fagus*, and *Quercus* pollen, in particular, are more abundant in Basin Pond than at Conroy Lake.

Zone I (1600 to 500 years ago) was characterized by a high PAR of *Tsuga* and *Fagus*, and relatively low amounts of *Pinus strobus* and *Quercus*. *Picea* pollen amounts were low from 1600 to 1000 years ago, and slowly increased between 1000 and 500 years ago. As at Conroy Lake, pollen of the hardwoods — *Ostrya/Carpinus*, *Ulmus*, and *Fraxinus* — was never particularly abundant. In Zone II (500 to 150 years ago) *Picea* PAR continued to increase, reaching values of 1500 grains/cm²/yr. *P. strobus* and *Quercus* pollen in-
TABLE I

Pollen accumulation rates (grains/cm²/year) of taxa not included on the pollen diagrams

<table>
<thead>
<tr>
<th>Years before 1974</th>
<th>Tilia</th>
<th>Juglans</th>
<th>Castanea</th>
<th>Populus</th>
<th>Picea</th>
</tr>
</thead>
<tbody>
<tr>
<td>1020</td>
<td>15</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>980</td>
<td></td>
<td></td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>940</td>
<td></td>
<td></td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>900</td>
<td>35</td>
<td></td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>860</td>
<td>29</td>
<td></td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>820</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>780</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>740</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>700</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>660</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>620</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>580</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>540</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>500</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>460</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>420</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>380</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>340</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>260</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>220</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ELY LAKE

<table>
<thead>
<tr>
<th>Years before 1974</th>
<th>Tilia</th>
<th>Juglans</th>
<th>Castanea</th>
<th>Populus</th>
<th>Picea</th>
</tr>
</thead>
<tbody>
<tr>
<td>1020</td>
<td>50</td>
<td>181</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>980</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>940</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>900</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>860</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>820</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>780</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>740</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>700</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>660</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>620</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>580</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>540</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>500</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>460</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>420</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>380</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>340</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>300</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>260</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>220</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>180</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>140</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>60</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
</tbody>
</table>

CLEAR POND

<table>
<thead>
<tr>
<th>Years before 1974</th>
<th>Tilia</th>
<th>Juglans</th>
<th>Castanea</th>
<th>Populus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1020</td>
<td>50</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>980</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>940</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>860</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>820</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>780</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>740</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>660</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>620</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>580</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>540</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>460</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>420</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>340</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>220</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
creased while \textit{Tsuga} and \textit{Fagus} decreased.

Zone III (150 years ago to the present) was characterized by a major increase in NAP. Unlike in the Conroy Lake pollen diagram, \textit{Alnus} and \textit{Populus} pollen did not greatly increase in this zone.

CLEAR POND

The Clear Pond PAR diagram was divided into four zones (Fig. 4). Level 1290 (years ago) was not plotted, as it had a total PAR value of 41,000 grains/cm$^2$/yr — four times that of the mean of the other samples. The percentages of this level were reasonable, however, and showed values intermediate between those of the adjacent two levels.

Zone I (1890 to 1250 years ago) was characterized by low values of \textit{Picea} pollen and relatively high accumulation rates of \textit{Tsuga} and \textit{Fagus} pollen. \textit{Pinus strobus} remained low in this and the subsequent zone, while \textit{Betula} pollen showed a slight long-term increase in this zone and in Zone II. \textit{Acer} PAR were relatively high at Clear Pond, attaining values greater than 500 grains/cm$^2$/yr in several sections of the diagram. \textit{Acer} remained constant at these relatively high values throughout the past 1600 years at this site.

\textit{Picea} PAR increased abruptly between 1200 and 1300 years ago. In Zone II (1250 to 500 years ago), \textit{Picea} PAR re-
mained between 1000 and 2000 grains/cm²/yr. Tsuga and Fagus pollen decreased. In Zone III (500 to 100 years ago) Picea pollen again increased, while Tsuga and Fagus steadily declined. Abies pollen was consistently present in Zone III. Most pollen taxa were little changed from Zone II. Although never particularly abundant, Ostrya/Carpinus, Ulmus, and Fraxinus were slightly less abundant in Zone III than in Zone I.

Zone IV (100 years to the present) is the European settlement period. NAP and Betula increased, while most tree pollen decreased in this zone.

ELY LAKE

The pollen accumulation rate diagram of Ely Lake (Fig. 5) was divided into four zones. Ely Lake is located to the south of the other three lakes, and there were no Abies and only occasional grains of Picea pollen in the sediment (Table I). Pollen types from trees of the southern deciduous forest, e.g. Carya, Juglans and Castanea, are important components of this diagram, and Quercus pollen is more abundant than at the other sites. Tsuga pollen is more abundant than at either Conroy Lake or Clear Pond, and has values comparable to those at Basin Pond.

In Zone I (2370 to 900 years ago) Pinus strobus, Quercus, and Castanea pollen steadily decreased, while Tsuga, Betula, and Fagus increased. The similarities of the profiles of Tsuga, Fagus and Betula in this diagram suggest that the dominant species of Betula at this site was Betula lutea.

In Zone II (900 to 400 years ago) Castanea PAR increased, reaching a maximum value of nearly 2000 grains/cm²/yr 700 years ago, and subsequently decreased in the younger portion of the zone. Quercus and P. strobus pollen increased in this zone, while Tsuga, Betula, and Fagus decreased. These trends reversed in Zone III (400 to 150 years ago) with most pollen types approaching values comparable to those at the top of Zone I. Alnus pollen was consistently present at low amounts in Zone III. In Zone IV (150 years ago to the present) NAP increased while most arboreal pollen decreased in abundance.

DISCUSSION

In making inferences about the vegetation from these pollen diagrams, we were guided by the interpretations of WEBB et al. (1983) relating pollen to vegetation in southern Quebec. At Conroy Lake a mixture of hemlock-hardwood forests and spruce-fir forests was regionally important in the late Holocene. The pollen sequence at Conroy Lake suggests a long term replacement of hardwoods by boreal forest elements. In Zone I Tsuga trees were abundant in the landscape around Conroy Lake, and remained important in the area in Zone II. By the time of European settlement, Picea trees had increased in the region. MOTT (1975) showed the beginnings of this increase in Picea in western New Brunswick, but the upper portions of some of his cores were truncated or the increase in Picea was undated. At Conroy Lake, quantities of Pinus strobus and Quercus pollen were low, and at these values, could have been blown in from a distance. P. strobus trees, however, were
probably present in low densities in the immediate area, as
this species frequently reproduces in gaps in the forests fol-
lowing disturbance (HIBBS, 1982). Throughout the past
1600 years, there remained significant numbers of Betula
trees in the landscape. Fagus and Acer pollen were relatively-
ly constant at low levels, although both species were proba-
ble relatively abundant on the landscape. Abies pollen
amounts were low, but these more or less constant values
in the past 2000 years indicate that Abies trees were
present in the area around Conroy Lake, because at the
present time Picea rubens and Abies balsamea are the
dominant trees over the whole landscape in northwestern
Maine, while hardwoods are limited to better soils (OOST-
ING and REED, 1944). To the east, in western New Brun-
swick, hardwoods such as Fagus grandifolia and Acer spp.
are equally important in the vegetation as the softwoods,
with the hardwoods more important at lower elevations and
the hardwoods showing the reverse trend (POWELL, 1984).
The area around Conroy Lake has low relief, and today
there is agriculture within 100 m of the lake, but all of these
species, and others such as Betula papyrifera and Populus
tremuloides are found in the immediate area (Swain, per-
sonal observation). The pollen diagram suggests that the
softwoods have increased in the recent past at the expense
of the hardwoods and Tsuga. Today, there are very few Tsu-
ga trees around the lake (Swain, personal observation).
ROGERS (1978) suggested that the low values of Tsuga
in many forests today was due to disturbance of the forests
associated with European settlement, but this decrease had
begun prior to settlement. Similar observations have been
made for Fagus (GAJEWSKI, 1983; BENNETT, 1985).

At Basin Pond and Clear Pond, a mesic hemlock-
hardwood forest with increasing Picea was prevalent during
the late Holocene. At Basin Pond, the values of pollen influx
suggest abundant numbers of Tsuga, Fagus, and Acer trees
in the vegetation, and the presence of Quercus and Betula.
Even after the transition to Zone 2, Tsuga and Fagus re-
maind abundant in the vegetation, and Quercus became a
more important component of the forest. P. strobos never
attained significant numbers. Although Picea pollen in-
creased throughout the time period, there are more rapid in-
creases around 1050 and 500 years ago. The first increase
at 1050 years ago was followed by an increase in Acer and
Tsuga, while the second increase at 500 years ago was ac-
companied by a decrease in Tsuga, Fagus and Acer and an
increase in Quercus and Pinus pollen accumulation rates.
However, Picea trees were never particularly abundant in
the landscape. At the present time, the range of Picea glau-
ca extends approximately to Basin Pond and P. rubens ex-
tends a little further to the south (FOWELLS, 1985). In-
terpretation of the Basin Pond core suggests that there has
been a relatively recent extension southward in the range of
one or both of these two species. North of Basin Pond,
along the Maine-Québec border, MOTT (1977) found that a
Picea-Betula zone replaced an earlier Acer-Fagus zone. The
date of this transition was about 1500 to 2000 years ago,
and generally coincides with the entire sequence from Ba-
sin Pond presented here. RICHARD (1978) found an in-
crease in Picea mariana in southern Québec at this time.

Although we did not separate the Picea pollen into species
in our study, none of the lakes has a bog surrounding it
(SWAIN, personal observation) and thus the species com-
prising the increase in this region was probably also P. glau-
ca or P. rubens. In northern New Hampshire, Picea pollen
was at low levels around 3000 years ago, and quickly in-
creased to greater than 10 % at 2000 years ago. Tsuga and
Fagus pollen decreased at this time, while few other types
showed any long term changes (LIKENS and DAVIS, 1975).

At Clear Pond in Zones I and II, Tsuga, Fagus and Acer
trees were abundant components of the forests in the region,
while neither P. strobos nor Quercus were particularly
significant. Tsuga and Fagus trees are characteristically
found in more mesic sites and in older forests in the Lake
George region (NICHOLSON et al., 1979) while P. strobos
and Quercus are early successional species in the Catskills
(McINTOSH, 1972). Values of Acer pollen are quite high,
and indicate the importance of Acer trees in the forest
around Clear Pond; Acer pollen values (which amount to 3-
7 %) were greater than those of the "érabilière" of southern
Québec (RICHARD, 1976). Picea pollen increased in impor-
tance, particularly in Zone III. In northern New York (Bran-
dreth Bog), OVERPECK (1985) showed a Picea pollen in-
crease to over 5 % at around the same time as at Clear
Pond (between 1000 and 1500 YBP at Brandeth Bog), and a
decrease in Tsuga and Fagus pollen in the past 1000 years.
Accumulation rates at Brandreth Bog are greater and more
variable than those at Clear Pond, probably because of a
sediment change at Brandreth Bog. The PAR results from
Clear Pond may be more representative of true changes in
pollen production during this time period, because there are
no sediment changes accompanying the pollen changes.

At Ely Lake, a hemlock-hardwood forest mixed with
southern deciduous taxa (Quercus, Castanea, Carvus, etc.)
was present in the late Holocene, while the relative impor-
tance of these elements changed over time. The values of
PAR at Ely Lake indicate significant amounts of Tsuga and
Fagus trees in the landscape. These species, and other
taxa such as Acer, Tilia, Fraxinus, Ulmus, Quercus, Beul",a,
and Populus are today present in the immediate vicin-
ty of the lake (Swain, personal observation). Castanea and Quer-
cus were consistently present in the region, especially dur-
ing the time represented by Zone III. In southeastern Penn-
sylvania and New Jersey, Quercus species, in combination
with Carvus (and Castanea prior to this century), are found on
drier sites, while Tsuga and the northern hardwoods are
found on more mesic sites (KEEVER, 1973; ROBICHAUD
and BUell, 1973; BUELL et al., 1966; OHMAN and
BUell, 1968). Tsuga is sensitive to drought and distur-
bance (ROGERS, 1978). The decline in Tsuga between
1100 and 500 years ago suggests that there was a
significant dry period in this interval.

The abundant taxa in all four cores show consistent
changes in PAR values that occur quickly (within a couple
hundred years) or persist for several centuries. In a previous
study (GAJEWSKI et al., 1985) we suggested that rapid
changes in the abundance of pollen in laminated sediments
represent real changes in the forest. We can now compare
the pollen chronologies at the four sites and attempt to infer possible causes of the changes. If an increase or decrease in a particular pollen taxon occurs simultaneously over a large area, this suggests a climatic cause.

The pollen sequences at Conroy Lake, Basin Pond and Clear Pond are broadly similar. These diagrams specify in more detail the late Holocene increase in *Picea* and other boreal forest taxa and the decrease of taxa of the conifer-hardwood forest along the southern border of the boreal forest that has been identified at numerous sites in northeastern United States and southeastern Canada (BERNABO and WEBB, 1977; WEBB et al., 1983; GAUDREAU and WEBB ; 1985). The pollen types that can be easily correlated between sites (e.g. *Picea*) are those that illustrate biome-level changes and which increase from negligible values in the middle Holocene to significant portions of the pollen rain by the present time. Alternatively, large-scale coherent changes can be seen in pollen types that reach their maximum values in this region (*Tsuga* and *Fagus*). The similarities in the profiles of these taxa indicate regional changes in the vegetation, although the particular sequence depends on the location. *Picea* increased at the northern sites while *Tsuga* and *Fagus* decreased, with more rapid changes occurring at 500 years ago and perhaps around 1200 to 1000 years ago. At these times, *Tsuga* and *Fagus* first decreased and then increased, while *Quercus* and *Castanea* showed the opposite trend at Ely Lake.

Many of the pollen types do not show patterns that can be correlated between sites. Pollen of some hardwood genera — *Ostrya/Carpinus*, *Ulmus*, *Fraxinus*, *Tilia* and *Acer* — were present in such low amounts that regional patterns cannot be determined. Other types — *Abies*, *Carya*, *Castanea* and *Juglans* — are only present in one or two diagrams, and thus regional patterns cannot be traced.

*Betula*, *Quercus*, and *Pinus strobus* pollen stratigraphy is more difficult to interpret for several reasons. *Betula* and *Quercus* pollen types include several species with different ecological tolerances and behaviors. All these taxa are prolific pollen producers, and at the values present in these cores, significant amounts could have been blown in from elsewhere. *Quercus* PAR increased at Basin Pond but showed no change at Clear Pond or Conroy Lake 400 years ago; *Quercus* PAR decreased at Ely Lake at this time. *P. strobus* values were relatively low at all sites; WEBB et al. (1983) indicate that 15 % of the pollen can be blown in from long distance. *P. strobus* increased between 500 years ago and settlement at Conroy Lake, Basin Pond and Clear Pond, while it decreased at Ely Lake. *Betula* pollen amounts indicate significant values at Basin and Conroy Lakes, but not necessarily at Clear and Ely Lakes. This may be due to the relatively greater importance of *B. papyrifera* trees at the Maine sites, while *B. lutea* trees were more important at the middle Atlantic sites. Because of the differences in the ecology of these species and the presence of other species of *Betula* in northeastern United States, these profiles are difficult to compare between sites. Interpretation of climatic change from these pollen diagrams is discussed in more detail in GAJEWSKI (1983).

Comparison of the timing of the more rapid changes in the four pollen records provides further evidence of the importance of late Holocene climatic changes on the vegetation in this region. More rapid changes in the pollen curves were clustered between 500 and 400 years ago and between 1200 and 900 years ago. Other late Holocene fossil data also show transitions at these times (SWAIN, 1978). The broad synchrony in the times of rapid changes, and the similarity of many of the pollen profiles of the four sites suggests the influence of century-scale climate changes on the vegetation of this region.

These cores provide further information about the complex history of several species in the forests of eastern North America. A dense array of closely-sampled and well-dated pollen sites could provide new information about the dynamics of vegetation and the factors affecting tree species at many time scales.

ACKNOWLEDGMENTS

This work was supported by NSF Grants ATM-8111455 and ATM-8219079. We would like to thank R. Steventon for assistance in the field and for processing the pollen samples. J. Kutzbach, T. Webb, and M. Winkler read various versions of the manuscript.

REFERENCES


— (1977): Late-Pleistocene and Holocene palynology in southeastern Québec, Geographie physique et Quaternaire, Vol. 31, p. 139-149.


We have assumed in this study that the laminations present in these cores are annual. Although we have not analyzed the laminations in detail, there are several lines of evidence that suggest that laminations found in small and deep lakes in temperate regions are annual. Several investigations in Scandinavia and eastern North America (e.g. CRAIG, 1972; DIGERFELDT et al., 1975; RENBERG, 1976; SAARNISTO, 1985; SAARNISTO et al., 1977; TOLOMEN, 1980; TOLOMEN, 1978) have demonstrated the annual nature of laminations such as those analyzed in this study (but see SIMOLA and TOLOMEN, 1981). In these and other laminated lakes (e.g. see SWAIN, 1978; GAJEWSKI et al., 1985), the European settlement horizon, an increase in non-arboreal pollen, dates at approximately the time documented by historical records, except for Conroy Lake (see below). In a previous study, we analyzed the pollen sequences from three lakes within one km of each other (GAJEWSKI et al., 1985). The pollen sequences for the three lakes were similar, suggesting a regular accumulation of sediment.

Conroy Lake date correction

After the pollen diagram for Conroy Lake was completed and plotted, the non-arboreal pollen rise (Zone III of Fig. 2), which in the northeast dates the arrival of European settlement (DAVIS, 1967), was dated at 225 "varve years ago" (AD 1740). However, FOBES (1944) determined that by the 1820's there were only a few settlements in Aroostook County; the major period of settlement didn't occur until after 1834, when the Bangor-Houlton military road was completed. Since the increase in NAP was so distinct and included pollen types such as Rumex, which were never present in the diagram prior to settlement, it was realized that there was some error in the lamination counts in the uppermost sediments. Consequently, the NAP zone (Zone III) base was set at 150 years ago. In all calculations and subsequent analysis on this core, we assumed that the uppermost samples contained seven years rather than ten years. No correction was applied below the settlement horizon, where the laminations were more distinct and easily counted compared to those above the horizon.

Several lines of reasoning contribute to the decision to correct only the uppermost 150 years. The uppermost sediment of lakes is usually flocculant and the most easily disturbed when the sampler penetrates the sediment. Experience indicates that this is the most difficult portion of the core to count. European settlement, which is a major disturbance in North American watersheds, has frequently altered the geochemistry of lakes (DAVIS and NORTON, 1978; BRUGAM, 1978), which could affect varve sedimentation. VUORINEN (1978) found changes in varve sedimentation following the introduction of agriculture in eastern Finland, although he still found only one varve deposited per year.

Subsequent to the analyses reported here, JOHNSTON (1981) independently determined multiple laminations in Conroy Lake for at least the past 60 years. He used several methods of dating the cores, including stratigraphic markers, $^{230}$Pb and $^{137}$Cs. He found indications of agriculture in the core sediment chemistry. The watershed of Conroy Lake is more disturbed than most of the other lakes used in this study (Swain, personal observation; see also JOHNSTON, 1981). Thus it seems valid to correct the uppermost dates, but whether this is true for the sediment further down is as yet unknown.