Article

"Late Holocene Pollen Stratigraphy in Four Northeastern United States Lakes"

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LATE HOLOCENE POLLEN STRATIGRAPHY IN FOUR NORTHEASTERN UNITED STATES LAKES

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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.

RÉSUMÉ *La stratigraphie pollinique de quatre lacs du nord-est des États-Unis à l'Holocène supérieur.* Quatre diagrammes polliniques des états du Maine, de New York et de Pennsylvanie illustrent de manière détaillée (40 ou 80 ans) les changements survenus dans la végétation du nord-est des États-Unis sur une période de 2000 ans. Les trois diagrammes des états du Maine et de New York enregistrent un accroissement continu de l'influx pollinique (PAR) de *Picea*. Il y a environ 1100 ans, *Tsuga* et *Fagus* ont subi une diminution, tandis que *Quercus* et *Castanea* ont augmenté à Ely Lake, dans le nord-est de la Pennsylvanie. Il y a 500 ans, *Tsuga* et *Fagus* ont considérablement diminué dans les états du Maine et de New York, alors que leur représentation pollinique augmentait dans le nord-est de la Pennsylvanie et que *Quercus* et *Castanea* diminuaient. Les influx polliniques des herbacés étaient minimes avant l'arrivée des Européens dans la région, après quoi ces taxons ont connu une augmentation subite.

ZUSAMMENFASSUNG *Pollen-Stratigraphie im späten Holozän in vier Seen Nordosten der Vereinigten Staaten.* Vier Pollen-Diagramme von Maine, New York und Pennsylvania geben detaillierte Auflösungs-Nachweise der Vegetationswechsel im Nordosten der Vereinigten Staaten während der letzten 2000 Jahre. Ein langfristiges Anwachsen der Pollen-Akkumulationsraten (PAR) von *Picea* trat an den drei Fundstellen in Maine und im Staat New York auf. Vor ungefähr 11000 Jahren, nahmen am Ely-See in Nordost-Pennsylvania *Tsuga* and *Fagus* ab und *Quercus* und *Castanea* zu. Vor ungefähr 500 Jahren nahmen in Maine und im Norden des staats New York *Tsuga* und *Fagus* stark ab, während in Nordost-Pennsylvania *Tsuga* und *Fagus* zunahmen und *Quercus* und *Castanea*-Pollen abnahmen. Die nicht von Bäumen stammenden PAR waren gering, bevor das Gebiet von Europäern besiedelt wurde, während danach die nicht von Bäumen stammenden Pollenarten plötzlich anwuchsen.

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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
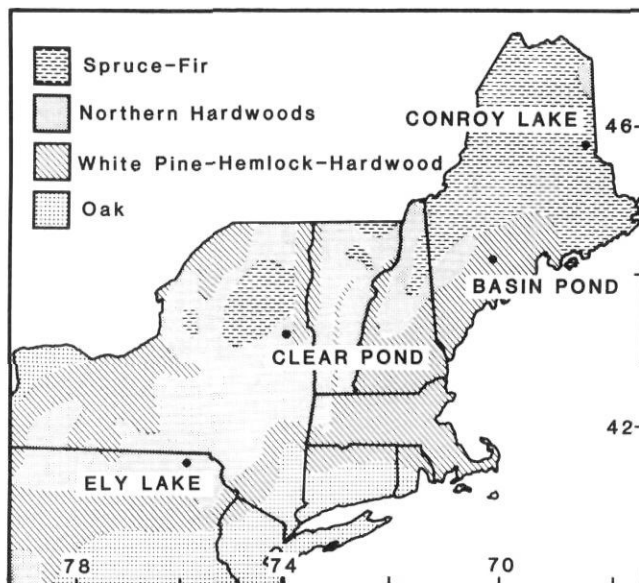

FIGURE 1. Location of lakes in northeastern United States. Forest types after LULL, 1968.

Localisation des lacs échantillonés dans le nord-est des États-Unis. Identification des types de forêts selon LULL, 1968.

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 cathetometer. 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 % HCl, concentrated HF and acetolysis 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 mimima 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-
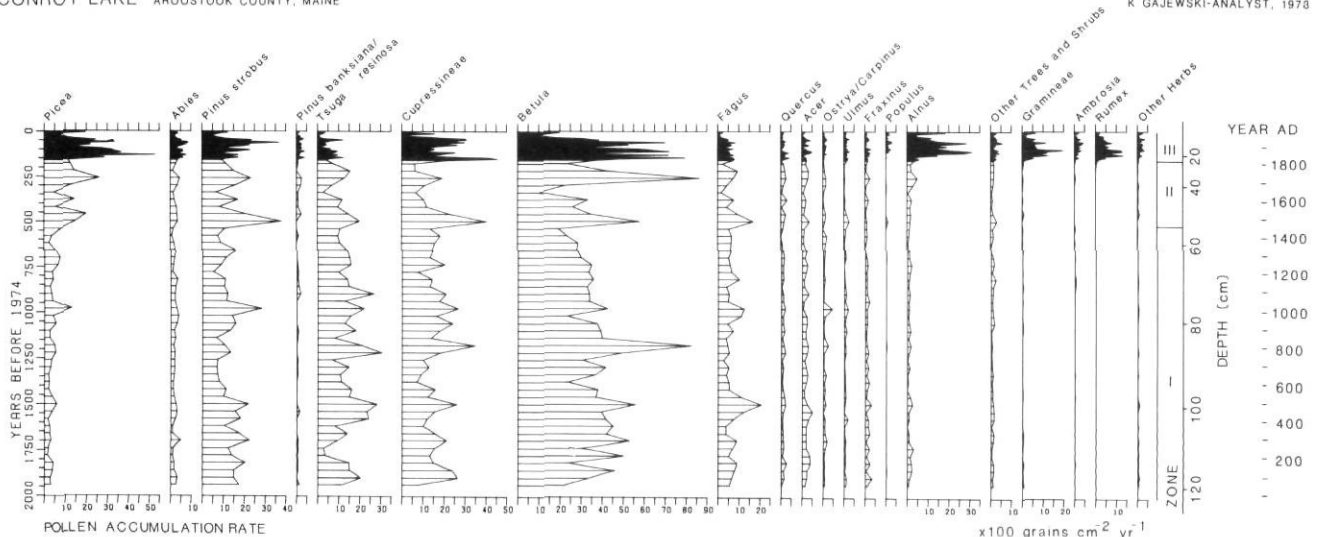

FIGURE 2. Pollen accumulation rate (PAR) diagram for Conroy Lake.

Diagramme de l'influx pollinique, Conroy Lake.

TABLE I

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

CONROY LAKE

Years before 1974	Tilia	Carya	Juglans	Castanea	Platanus
7			23		
14		20			20
35		24			
42	39				
49					59
77	48				
84				42	
91					24
105				64	
119		53			
133				139	70
140				24	
147				137	
154					45
161			29		29
180	18	18			
220	28			55	
300		29			
340		17			
380			23		
460				47	
500				52	
580				50	25
620		18			
700			20	20	20
740		26	26	26	
780				38	
900	35				
980			48		
1020					31
1060	35	35			
1180				35	
1260				20	
1340		24		24	24
1380		18			18
1460					27
1580			30	30	30
1620					25
1660					31
1820		32			
1860		28		28	28
1940				22	

ELY LAKE

Years before 1974	Populus	Picea
50	181	
90	22	22
180		29
300	30	
540		26
720	28	
780		22
860		21
1080	26	
1180		23
2050	28	
2210		17

BASIN POND

Years before 1974	Tilia	Carya	Juglans	Castanea	Platanus
15			59		
25		47		94	
35				95	
55	38	38		38	
65		16	16	31	16
75	10				
85				88	
95	50			101	
115					63
125					33
135		68			34
155	45				
185		32	32	32	
215		48		24	
255		33		99	
295		54			
335	33	65			
375		25	25		
415				38	38
455					27
495				46	46
535		37		37	
575	37			37	
615		33		33	
645		31		31	
655	28			28	28
695	32	63	32	63	
735	23		23	23	
775	40			79	
815		63			32
895		26			
935		45			45
975				76	
1015		20		20	
1135					61
1055	26			26	
1095				29	
1135				31	
1175	41	41			
1255				19	57
1295		35			
1335		29		15	15
1375		46		46	92
1415		17	17		
1455	26		52	26	26
1495		68	34		
1535	26			26	26
1575	50	25			
1605		63		32	

CLEAR POND

Years before 1974	Populus
50	32
250	26
290	77
730	35
810	78
890	24

creased while *Tsuga* and *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, *Alnus* and *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/cm²/yr — four times that of the mean of the other samples. The percentages of this level were reasonable, however, and showed values in-

termediate between those of the adjacent two levels.

Zone I (1890 to 1250 years ago) was characterized by low values of *Picea* pollen and relatively high accumulation rates of *Tsuga* and *Fagus* pollen. *Pinus strobus* remained low in this and the subsequent zone, while *Betula* pollen showed a slight long-term increase in this zone and in Zone II. *Acer* PAR were relatively high at Clear Pond, attaining values greater than 500 grains/cm²/yr in several sections of the diagram. *Acer* remained constant at these relatively high values throughout the past 1600 years at this site.

Picea PAR increased abruptly between 1200 and 1300 years ago. In Zone II (1250 to 500 years ago), *Picea* PAR re-
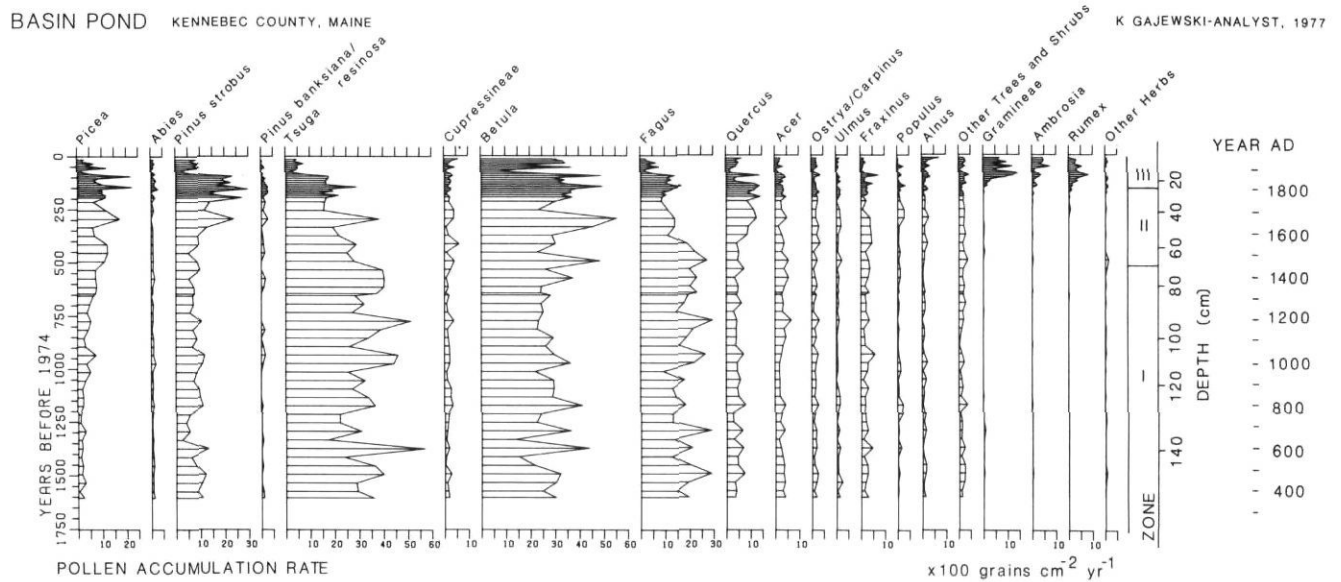

FIGURE 3. Pollen accumulation rate (PAR) diagram for Basin Pond.

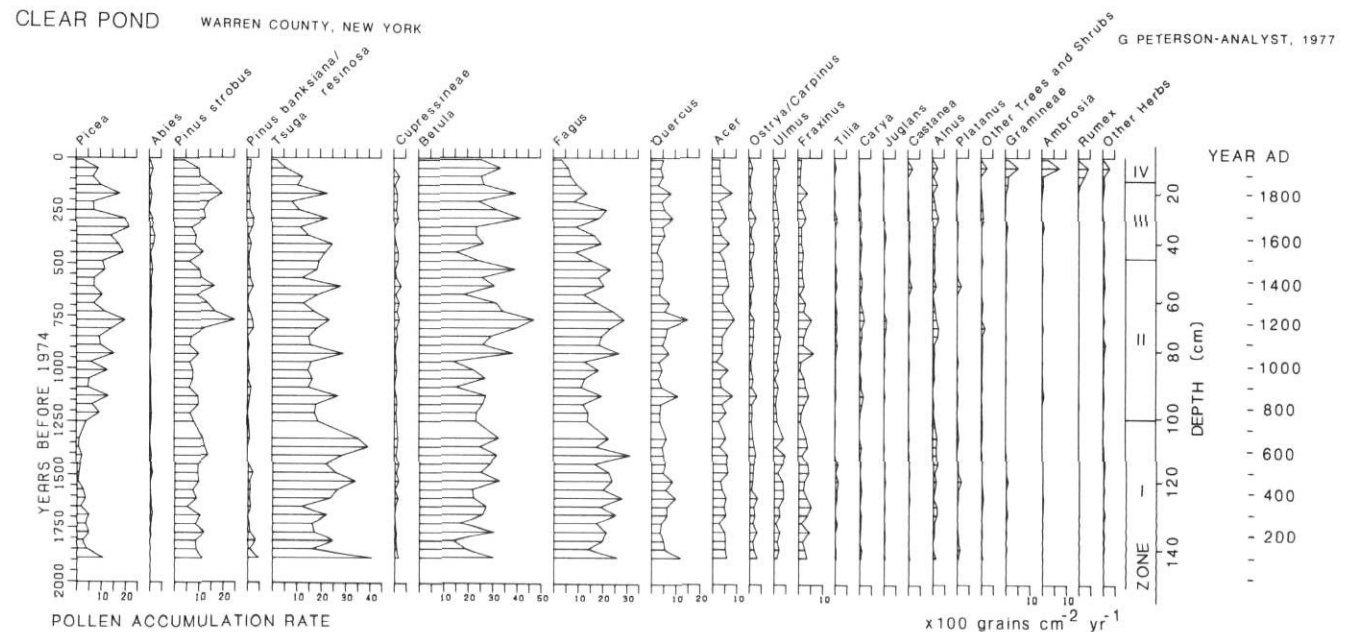*Diagramme de l'influx pollinique, Basin Pond.*

FIGURE 4. Pollen accumulation rate (PAR) diagram for Clear Pond.

Diagramme de l'influx pollinique, Clear Pond.

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 Québec. 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
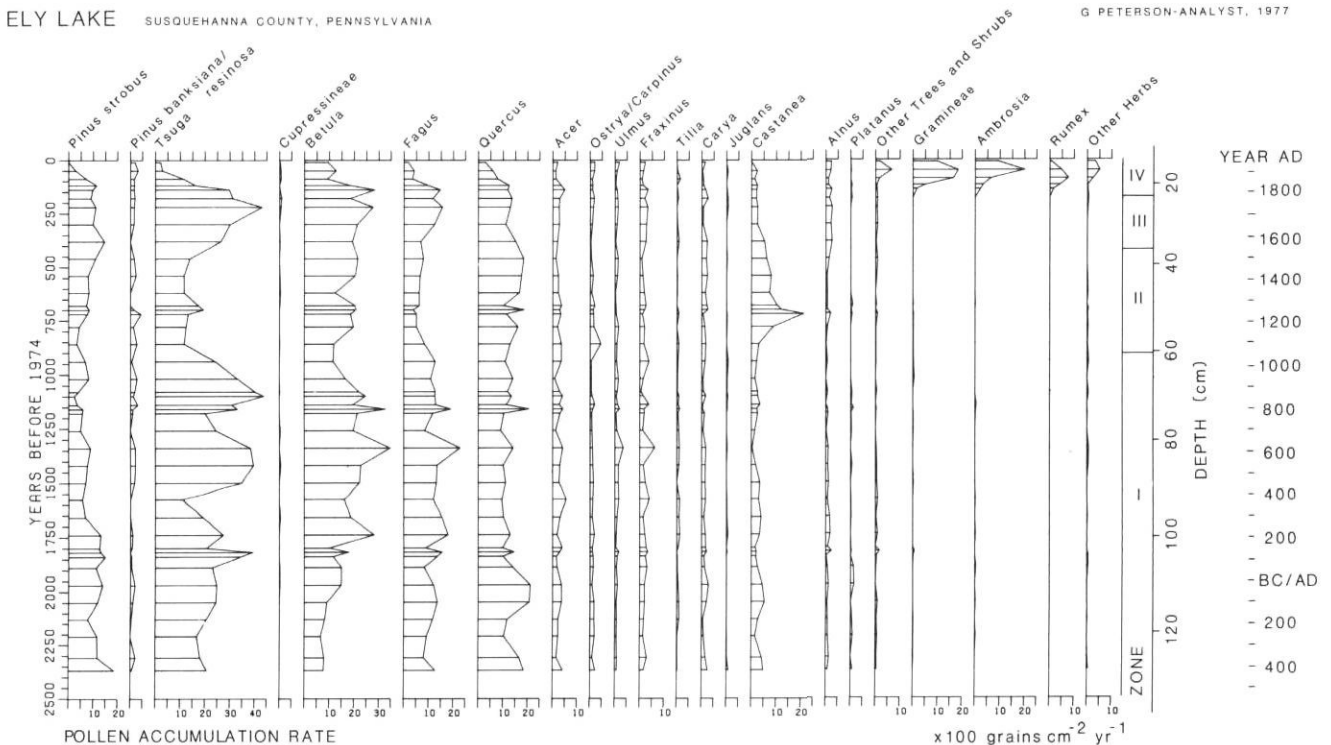

FIGURE 5.   Pollen accumulation rate (PAR) diagram for Ely Lake.   *Diagramme de l'influx pollinique, Ely Lake.*

probably present in low densities in the immediate area, as this species frequently reproduces in gaps in the forests following disturbance (HIBBS, 1982). Throughout the past 1600 years, there remained significant numbers of *Betula* trees in the landscape. *Fagus* and *Acer* pollen were relatively constant at low levels, although both species were probably 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 (OOSTING and REED, 1944). To the east, in western New Brunswick, hardwoods such as *Fagus grandifolia* and *Acer* spp. are equally important in the vegetation as the softwoods, with the softwoods 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, personal 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 *Tsuga* 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* remained abundant in the vegetation, and *Quercus* became a more important component of the forest. *P. strobus* never attained significant numbers. Although *Picea* pollen increased throughout the time period, there are more rapid increases 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 accompanied 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 glauca* extends approximately to Basin Pond and *P. rubens* extends a little further to the south (FOWELLS, 1965). Interpretation 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 Basin Pond presented here. RICHARD (1978) found an increase 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 comprising the increase in this region was probably also *P. glauca* or *P. rubens*. In northern New Hampshire, *Picea* pollen was at low levels around 3000 years ago, and quickly increased 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. strobus* 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. strobus* 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 "érablière" of southern Québec (RICHARD, 1976). *Picea* pollen increased in importance, particularly in Zone III. In northern New York (Brandreth Bog), OVERPECK (1985) showed a *Picea* pollen increase 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, Carya,* etc.) was present in the late Holocene, while the relative importance 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, Betula,* and *Populus* are today present in the immediate vicinity of the lake (Swain, personal observation). *Castanea* and *Quercus* were consistently present in the region, especially during the time represented by Zone III. In southeastern Pennsylvania and New Jersey, *Quercus* species, in combination with *Carya* (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 disturbance (ROGERS, 1978). The decline in *Tsuga* pollen 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 diagram 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 behaviours. All three 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 synchroneity 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-samples and well-dated pollen sites could provide new information about the dynamics of vegetation and the factors affecting tree species at many time scales.

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APPENDIX I

CORE CHRONOLOGIES

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 ; TOLONEN, 1980 ; TOLONEN, 1978) have demonstrated the annual nature of laminations such as those analyzed in this study (but see SIMOLA and TOLONEN, 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.