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Forest Changes in the Great Lakes Region at 5-7 ka BP
Évolution de la forêt dans la région des Grands Lacs entre 5 et 7 ka
Entwicklung des Waldes im Gebiet der Großen Seen um 5-7 ka v.u.Z.

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Résumé de l'article

La stratigraphie pollinique établie à partir de 90 sites dans la région des Grands Lacs et en bordure rendent compte de l'évolution de la forêt entre 5 et 7 ka. À 7 ka, le hêtre (Fagus grandifolia) avait envahi la forêt à chênes et à caryers (Quercus-Carya) du sud du Michigan et la pruche (Tsuga canadensis) et le hêtre, la forêt du sud de l'Ontario dominée par le pin blanc (Pinus strobus). Au même moment, dans son expansion vers le nord, au delà de sa limite septentrionale actuelle, le pin blanc a remplacé le pin gris (P. banksiana). Les changements survenus vers 5 et 6 ka ont été dominés par l'extension de la zone de répartition du hêtre et de la pruche vers le nord, par la progression vers le nord du thuya occidental (Cupressineae) et de la migration méridionale du pin blanc vers le bassin du lac Michigan. La migration du hêtre et de la pruche (160 m ans^{-1} et 290 m ans1^{-1}, respectivement) a pu être influencée par le climat frais et humide créé par la présence des Grands Lacs Nipissing combinée au réchauffement régional prononcé. Le pin blanc et le thuya occidental ont réagi au réchauffement à l'échelle régionale et à la diminution des précipitations, tandis que le bouleau (Betula) et l'aulne (Aider) ont d'abord été sensibles aux feux occasionnés par le climat chaud et sec. L'écotone de la forêt boréale et de la forêt mixte a migré de 140 km vers le nord entre 5 et 7 ka, en comparaison des 60-70 km pour l'écotone de la forêt mixte et de la forêt de feuillus.

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FOREST CHANGES IN THE GREAT LAKES REGION AT 5-7 KA BP

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ABSTRACT Pollen stratigraphy from 90 sites in and bordering the Great Lakes record the 5-7 ka history of forest development of the Great Lakes region. By 7 ka beech (*Fagus grandifolia*) had invaded the oak-hickory (*Quercus-Carya*) forest of lower Michigan and hemlock (*Tsuga canadensis*) and beech the white pine (*Pinus strobus*)-dominated forest of southern Ontario. At the same time, white pine replaced jack pine (*P. banksiana*) as it expanded northward to the Clay Belt beyond its present-day range. Forest changes at 6 and 5 ka were dominated by range extensions of beech and hemlock in a northwesterly direction, by northward expansion of eastern white cedar (Cupressineae), and southward migration of white pine into the Michigan basin. The beech and hemlock migrations (160 m yr^{-1} and 280 m yr^{-1}, respectively) may have been influenced by the cool-moist climate generated by the Nipissing Great Lakes in combination with enhanced regional warming. White pine and eastern white cedar responded to regional warming and reduced precipitation, whereas birch (*Betula*) and alder (*Alnus*) may have been influenced more by fire activity caused by the warm-dry climate. The boreal-mixed forest ecotone was displaced 140 km northward at 5-7 ka compared to 60-70 km for the mixed-deciduous forest ecotone.

RÉSUMÉ *Évolution de la forêt dans la région des Grands Lacs entre 5 et 7 ka.* La stratigraphie pollinique établie à partir de 90 sites dans la région des Grands Lacs et en bordure rendent compte de l'évolution de la forêt entre 5 et 7 ka. À 7 ka, le hêtre (*Fagus grandifolia*) avait envahi la forêt à chênes et à caryers (*Quercus-Carya*) du sud du Michigan et la pruche (*Tsuga canadensis*) et le hêtre, la forêt du sud de l'Ontario dominée par le pin blanc (*Pinus strobus*). Au même moment, dans son expansion vers le nord, au delà de sa limite septentrionale actuelle, le pin blanc a remplacé le pin gris (*P. banksiana*). Les changements survenus vers 5 et 6 ka ont été dominés par l'extension de la zone de répartition du hêtre et de la pruche vers le nord, par la progression vers le nord du thuya occidental (Cupressineae) et de la migration méridionale du pin blanc vers le bassin du lac Michigan. La migration du hêtre et de la pruche (160 m ans^{-1} et 290 m ans^{-1}, respectivement) a pu être influencée par le climat frais et humide créé par la présence des Grands Lacs Nipissing combinée au réchauffement régional prononcé. Le pin blanc et le thuya occidental ont réagi au réchauffement à l'échelle régionale et à la diminution des précipitations, tandis que le bouleau (*Betula*) et l'aulne (*Alder*) ont d'abord été sensibles aux feux occasionnés par le climat chaud et sec. L'écotone de la forêt boréale et de la forêt mixte a migré de 140 km vers le nord entre 5 et 7 ka, en comparaison des 60-70 km pour l'écotone de la forêt mixte et de la forêt de feuillus.

ZUSAMMENFASSUNG *Entwicklung des Waldes im Gebiet der Großen Seen um 5-7 ka v.u.Z.* Die Pollen-Stratigraphie von 90 Plätzen im Gebiet der Großen Seen und daran angrenzend belegt die Geschichte der Waldentwicklung in diesem Gebiet zwischen 5-7 ka. Um 7 ka war die Buche (Fagus grandifolia) in den Eichen– und Hickory-Wald (Quercus-Carya) des südlichen Michigan eingedrungen und die Hemlocktanne (Tsuga canadensis) und die Buche in den von der Weißkiefer (Pinus strobus) beherrschten Wald von Süd-Ontario. Zur selben Zeit ersetzte die Weißkiefer die Graukiefer (P. banksiana) indem sie nordwärts über ihre heutige nördliche Ausdehnung hinaus bis zum Clay Belt vordrang. Die Waldveränderungen um 6 und 5 ka waren durch die Ausdehnung der Reichweite von Buche und Hemlocktanne in nordwestlicher Richtung, durch die nördliche Ausdehnung der östlichen weißen Zeder (Cupressineae) und durch die Südwärtswanderung der Weißkiefer in das Becken von Michigan beherrscht. Die Wanderungen von Buche und Hemlocktanne (160 m Jahre^{-1} bzw. 280 m Jahre^{-1}) können durch das kühl-feuchte Klima, das von den Großen Nipissing-Seen hervorgerufen wurde, kombiniert mit einer erhöhten regionalen Aufwärmung beeinflußt worden sein. Weißkiefer und östliche weiße Zeder reagierten auf regionale Erwärmung und verminderte Niederschläge, wohingegen Birke (Betula) und Erle (Alnus) wohl mehr durch Brände aufgrund des warmen trockenen Klimas beeinflußt wurden. Die Übergangszone des nördlichen Mischwaldes verschob sich 140 km nordwärts um 5-7 ka verglichen mit 60-70 km für die Ubergangszone des Laubmischwaldes.

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INTRODUCTION

The Holocene vegetation and climate history of the Great Lakes region is well-known (Bartlein *et al.*, 1984; Bartlein and Webb, 1985; Ritchie, 1987; COHMAP Members, 1988; Jacobson *et al.*, 1987; Webb 1987, 1988; Webb *et al.*, 1983, 1993). In brief, the early Holocene period (10-8 ka) was marked by rapid rates of vegetation change corresponding with abrupt climatic warming. The middle Holocene interval (8-4 ka) was characterized by range expansions of some forest components under the influence of maximum warmth and dryness, followed, in late Holocene time (4 ka-present), by gradual temperature decreases and resultant southward shifts of other forest elements. The 6 ka time slice is distinguished in the Great Lakes region by mean July temperatures of 1°C higher than today and farther northward displacement than today of the region having the steepest temperature gradient (Bartlein and Webb, 1985).

The distribution of Holocene pollen records in Ontario and bordering States in United States is shown in Webb (1988), Webb *et al.* (1993) and in recent syntheses by Holloway and Bryant (1985), Karrow and Warner (1990) and Anderson and Lewis (1992). Pollen stratigraphy for the 5-7 ka time slice is incomplete in that some records only encompass the early Holocene and earlier period, others commence only in the late Holocene and postdate 6 ka. Some regions, such as mid-central Ontario, have a large number of sites, whereas in northern Ontario the distribution of sites is scanty.

In this study, pollen records from the drainage basin of the Great Lakes (Ontario and lake states in United States, Fig. 1) are examined as a basis to interpret the vegetation composition and the migrational positions of key tree genera in the forest over the period 5 to 7 ka. Rather than just a simple snapshot at 6 ka, the 5-7 ka interval is discussed to observe the direction and intensity of any change occurring at this time. The physical presence of the Great Lakes as a migrational barrier and climatic influence, the relationship between vegetation composition and climate and, where possible, linkages to hydrological changes (past water-level fluctuations including groundwater, areal extent of the former Lakes) in the drainage basins will be discussed.

REGIONAL FEATURES

The Great Lakes basin is part of the western sector of the St. Lawrence physiographic lowland region. It is bounded to the north, west and south by contiguous highlands with disjunct highlands occurring east and west of Lake Huron and Georgian Bay basins indicated by the 305 m contour in Figure 2. Elevations of the lake surfaces drop from 183 m asl in Lake Superior, to 176 m in Lakes Michigan, Huron and Georgian Bay, to 174 m in Lake Erie, to 75 m in Lake Ontario.

Detailed descriptions of the present-day forest cover and modern climate data of the Great Lakes region are presented elsewhere (Brown *et al.*, 1968; Chapman and Thomas, 1968; Bennett, 1987; Liu, 1990) and need not be

FIGURE 1. Great Lakes region as defined in this study showing location of features discussed in text. Inset shows the study area as part of the national picture.

Carte de la région des Grands Lacs telle que définie dans la présente étude montrant la localisation des entités dont on parle dans le texte.

reiterated here. The region cuts across the boundaries of three major vegetation associations, the Deciduous, Mixed and Boreal Forests (Fig. 2). Prairie and Tundra Woodland presently lie outside the Great Lakes but prairie outliers in Michigan, Pennsylvania and Ontario (Reznicek and Maycock, 1983) are remnants of an earlier (middle Holocene) Prairie extension into the Great Lakes region. It is significant to note that the south-north change in forest cover (from south of to north of the Great Lakes) is accompanied by a 7°C mean July temperature gradient (Bartlein and Webb, 1985).

The climate of southern Ontario is strongly affected by the ameliorating effect of the Great Lakes. Lake Huron and Georgian Bay exert the greatest influence. Prevailing winds crossing these lake basins result in generally high precipitation in the Dundalk Upland region to the lee of these lakes (Fig. 1). Areas south and east of this influence, *i.e.*, south-central and southwest Ontario are drought prone in that they experience longer dry periods especially during summer than other regions of Ontario (Brown *et al.*, 1968).

Lake Superior exerts a similar climatic effect on the land areas to the east and northeast of the lake. Mean annual precipitation is generally highest on the lee easterly shores of the lake but decreases substantially eastward inland from the lake (Chapman and Thomas, 1968). Like Lake Huron, the prevailing westerlies likely loose much of their moisture as they cross the highlands at the eastern end of the lake. By the time the westerlies reach areas east and northeast of Lake Superior they have lost much of their moisture.

Laurentide Ice retreated from the Great Lakes region by about 8 ka (Lewis *et al.*, in press). The 7-5 ka period was influenced by continued differential rebound of the northern Lake Huron and Georgian Bay region and subsequent hydrological changes associated with the evolution of the Nipissing Great Lakes (Lewis *et al.*, in press).

THE DATABASE AND TECHNIQUES

Pollen records used in this synthesis are from the Great Lakes and the bordering drainage basin (Fig. 2, Table I). The majority of the sites are existing published percentage diagrams most of which are based on a pollen sum of tree, shrub and herb pollen excluding aquatic pollen. Although the pollen records from the Great Lakes are, for the most part, correlative with those on land, the former lack suitable materials for dating and pollen preservation is often less reliable. The database comprises some 90 pollen records and is dominated by Ontario sites but includes key sites in the lake states of New York, Ohio, Michigan, Wisconsin and Minnesota. Figure 3 (A-J) shows abbreviated pollen diagrams that represent deciduous, mixed and boreal forest associations existing at 5-7 ka. Dominant and other key taxa in the regional pollen spectra at the time include *Quercus* (oak), *Ulmus* (elm), *Fagus* (beech), *Acer* (maple), *Carya* (hickory), *Tilia* (basswood), *Pinus strobus* (white pine), *Tsuga* (hemlock), *Betula* (birch), *Alnus* (alder), *Picea* (spruce), *Pinus banksiana* (jack pine) and Cupressineae (white cedar). Reference radiocarbon dates and the estimated 5-7 ka time slice are placed on each pollen diagram;

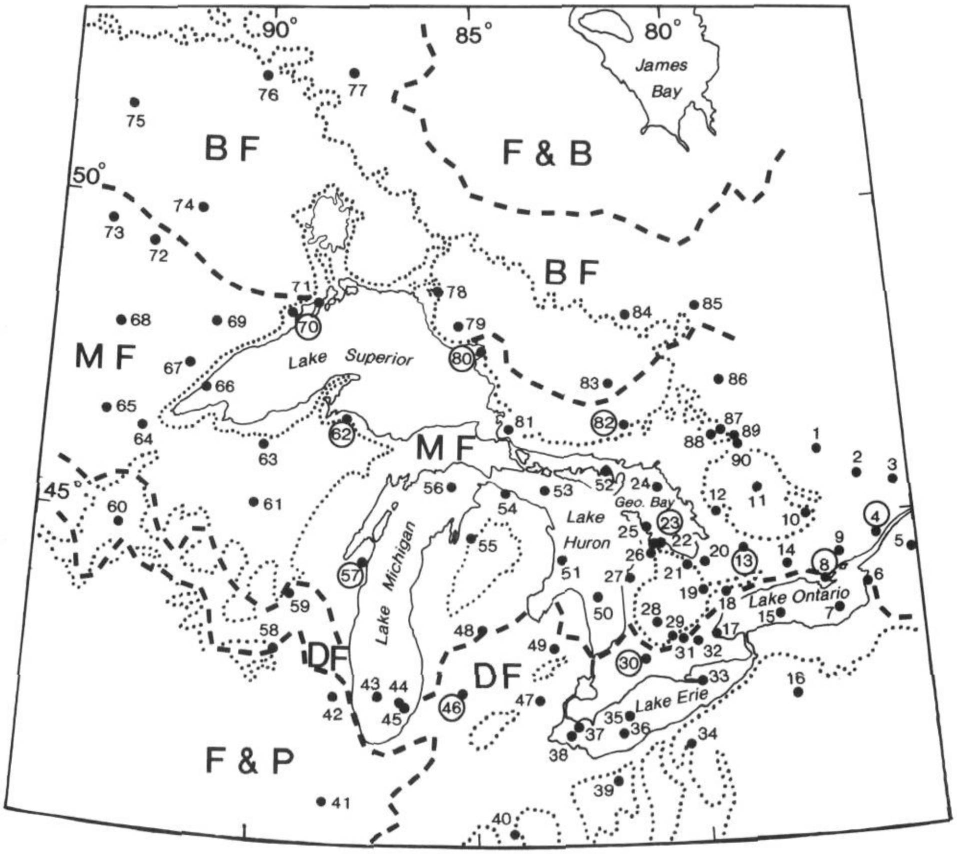


FIGURE 2. Great Lakes region showing pollen site locations, the 305 m elevation contour (dotted line) and major forest regions (F & P= Forest and Prairie; D F = Deciduous Forest; M F = Mixed Forest; B F = Boreal Forest; F & B = Forest and Barren). Circled sites indicate pollen diagrams present in this study.

Carte de la région des Grands Lacs montrant la localisation des sites polliniques, la courbe des 305 m (pointillé) et les principales régions forestières (F & P = forêts et prairies; D F = forêts de décidus; M F = forêts mixtes; B F = forêts boréales; F & B = forêts et terrains dénudés). Les diagrammes polliniques présentés proviennent des sites encerclés.

TABLE I

List of sites used in 5-7 ka synthesis of the Great Lakes region

Site No., Name and Elevation (m)	Lat: Long:	Reference(s)	Site No., Name and elevation	Lat: Long:	Reference(s):
1. Perch Lake, Ontario (145)	46° 02' 77° 32'	Terasmae (1980) Terasmae and McAtee (1979)	46. Wintergreen Lake, Michigan (283)	42° 24' 86° 39'	Manny et al. (1978)
2. Ramsay Lake, Quebec (200)	45° 36' 76° 06'	Mott and Farley-Gill (1981)	47. Frains Lake, Michigan (271)	42° 20' 83° 38'	Kerfoot (1974)
3. McKay Lake, Ontario (46)	45° 27' 75° 18'	Anderson (1987); R.N. McNeely (pers. comm., 1994)	48. Vestaburg Bog, Michigan (255)	43° 25' 84° 53'	Gilliam et al. (1967)
4. Lambs Pond, Ontario (105)	44°39' 75°48'	Anderson (1987)	49. Chippewa Bog, Michigan (270)	43° 07' 83° 14'	Bailey and Ahearn (1981)
5. Boyd Pond, New York (265)	44° 23' 75° 05'	Anderson (1989)	50. 69-02-01-15, Lake Huron (176)	43° 54' 82° 17'	Woodend (1983)
6. Henderson Hbr. Lake Ontario (75)	43° 54' 76° 11'	Unpublished data (GSC)	51. Core M-17, Lake Huron (176)	44° 30' 83° 08'	Lewis and Anderson (1989)
7. Core 70-E30, Lake Ontario (75)	43° 54' 76° 54'	J.H. McAndrews, unpubl. data	52. Greenbush Bog, Ontario (312)	45° 56' 82° 00'	Warner et al. (1984)
8. Bay of Quinte, Lake Ontario (75)	44° 02' 77° 05'	Unpublished data (GSC)	53. M Core, Lake Huron (176)	45° 37' 83° 23'	Zilans (1985)
9. Harrowsmith Bog, Ontario (158)	44° 25' 76° 42'	Terasmae (1968)	54. Lake Sixteen, Michigan (216)	45° 36' 84° 19'	Futyma and Miller (1986)
10. Weslemkoon L., Ontario (316)	45° 02' 77° 26'	Edwards and McAndrews (1989)	55. Green Lake, Michigan (350)	44° 53' 85° 07'	Lawrenz (1975)
11. Found Lake, Ontario (470)	45° 33' 78° 38'	McAndrews (1981)	56. Beaver Island, Michigan (230)	45° 40' 85° 33'	Kapp et al. (1969)
12. Nutt Lake, Ontario (305)	45° 13' 79° 27'	Bennett (1987)	57. Seidel Lake, Wisconsin (219)	44° 27' 87° 31'	West (1961)
13. Victoria Road Bog, Ontario (256)	44° 37' 78° 57'	Terasmae (1968)	58. Blue Mounds Cr., Wisconsin (335)	43° 05' 89° 52'	Davis (1977)
14. Barry Lake, Ontario (207)	44° 18' 77° 55'	McAndrews (1984)	59. Disterhaft Farm B., Wisconsin (329)	43° 55' 89° 10'	West (1961); Bender et al. (1971)
15. 68-17-5, Lake Ontario (75)	43° 33' 78° 09'	McAndrews (1971; 1973)	60. Kirchner Marsh, Minnesota (254)	44° 50' 93° 07'	Wright et al. (1963)
16. Belmont Bog, New York (497)	42° 15' 77° 55'	Spear and Miller (1976)	61. Wood Lake, Wisconsin (350)	45° 20' 90° 05'	Heide (1981)
17. Hamilton Harbour, Lake Ontario (75)	43° 17' 79° 52'	Unpublished data (GSC)	62. Lost Lake, Michigan (500)	46° 43' 87° 58'	Brubaker (1975)
18. Van Nostrand Lake, Ontario (297)	44° 00' 79° 23'	McAndrews (1970)	63. Lake Mary, Wisconsin (488)	46° 15' 89° 54'	Webb (1974)
19. Ballycroy Bog, Ontario (286)	43° 58' 79° 52'	Anderson (1971)	64. Jacobson Lake, Minnesota (324)	46° 25' 92° 43'	Wright and Watts (1969)
20. Minesing Swamp Ontario (189)	44° 26' 79° 49'	Fitzgerald (1985)	65. Rossburg Bog, Minnesota (372)	46° 35' 93° 36'	Wright and Watts (1969)
21. Edward Lake, Ontario (504)	44° 22' 80° 15'	McAndrews (1981)	66. Core 72-1, Lake Superior (183)	47° 09' 91° 20'	Maher (1977)
22. 68-1-17, Georgian Bay (176)	44° 44' 80° 52'	Author's unpublished files	67. Weber Lake, Minnesota (567)	47° 28' 91° 40'	Fries (1962)

Site No., Name and Elevation (m)	Lat: Long:	Reference(s)	Site No., Name and elevation	Lat: Long:	Reference(s):
23. Charles Lake, Ontario (247)	44° 45' 81° 01'	Bailey, R. personal communication (1973)	68. Myrtle Lake, Minnesota (393)	47° 58' 93° 23'	Janssen (1968)
24. 73-05-002-10, Georgian Bay (176)	45° 36' 80° 48'	McAtee (1977)	69. Lake of the Clouds, Minnesota (453)	48° 09' 91° 07'	Craig (1972)
25. Hope Bay, Georgian Bay (176)	44° 55' 81° 07'	Lewis and Anderson (1989)	70. Cummins Pond, Ontario (229)	48° 24' 89° 20'	Julig et al. (1990)
26. Townline Lake, Ontario (238)	44° 33' 81° 04'	Anderson (1971)	71. Pass Lake, Ontario (251)	48° 34' 88° 44'	McAndrews (1976)
27. Kincardine Bog, Ontario (196)	44° 09' 81° 39'	Karrow et al. (1975)	72. Rattle Lake, Ontario (460)	49° 29' 92° 42'	Björck (1985)
28. Ellice Bog, Ontario (369)	43° 29' 80° 57'	Anderson et al. (1989)	73. Hayes Lake, Ontario (325)	49° 35' 93° 45'	McAndrews (1982)
29. Maplehurst Lake, Ontario (300)	43° 13' 80° 39'	Mott and Farley-Gill (1978)	74. Sioux Pond, Ontario (410)	49° 56' 91° 34'	Björck (1985)
30. Pond Mills Pond, Ontario (268)	42° 57' 81° 12'	McAndrews (1981)	75. Nungesser Lake, Ontario (391)	51° 28' 93° 35'	Terasmae (1967)
31. Hams Lake, Ontario (282)	43° 14' 80° 25'	Bennett (1987)	76. Cristal Lake, Ontario (355)	52° 07' 90° 05'	Björck (1985)
32. Copetown Bog, Ontario (244)	43° 13' 80° 03'	Karrow (1987)	77. Attawapiskat Lake, Ontario (242)	52° 13' 87° 55'	Terasmae (1968)
33. Long Point, Lake Erie (174)	42° 33' 80° 03'	Lewis and Anderson (1992)	78. Ring Lake, Ontario (324)	48° 46' 85° 51'	McIntyre et al. (1991)
34. Crystal Lake, Pennsylvania (320)	41° 33' 80° 22'	Walker and Hartman (1960)	79. Thane Lake, Ontario (420)	48° 22' 85° 04'	Terasmae (1967)
35. Core 13194, Lake Erie (174)	42° 05' 81° 40'	Fritz et al. (1975) Author's unpubl. files	80. Alfies Lake, Ontario (288)	47° 53' 84° 52'	Saarnisto (1975)
36. Core 2226, Lake Erie (174)	41° 45' 81° 55'	Lewis et al. (1966)	81. Quadrangle Lake, Ontario (314)	46° 35' 84° 25'	Terasmae (1967)
37. Core 68-6, Lake Erie (174)	41° 55' 82° 45'	Lewis and Anderson (1989)	82. Nina Lake, Ontario (380)	46° 36' 81° 30'	Liu (1990)
38. Core 1240, Lake Erie (174)	41° 46' 82° 57'	Lewis and Anderson (1989)	83. Jack Lake, Ontario (430)	47° 19' 81° 46'	Liu (1990)
39. Quillin site, Ohio (305)	41° 00' 41° 00'	Shane (1987)	84. Lake Six, Ontario (305)	48° 24' 81° 19'	Liu (1990)
40. Stotzel-Leis site, Ohio (312)	40° 13' 84° 14'	Shane (1987)	85. Lac Yelle, Ontario (355)	48° 30' 79° 38'	Richard (1980)
41. Chatsworth Bog, Illinois (219)	40° 40' 88° 20'	King (1981)	86. Lac Louis, Ontario (300)	47° 17' 79° 07'	Vincent (1973)
42. Volo Bog, Illinois (229)	42° 21' 88° 11'	King (1981)	87. North Bay Bog, Ontario (390)	46° 27' 79° 28'	Terasmae (1968)
43. Core 1001-3A, Lake Michigan (176)	42° 22' 87° 11'	King et al. (1976)	88. Alderdale Bog, Ontario (358)	46° 03' 79° 12'	Terasmae (1968)
44. Core 1000-3C, Lake Michigan (176)	42° 18' 86° 42'	King et al. (1976)	89. Lac Bastien, Ontario (305)	46° 24' 78° 55'	Bennett (1987)
45. Core 969-2A, Lake Michigan (176)	42° 14' 86° 39'	King et al. (1976)	90. Morel Lake, Ontario (194)	46° 16' 78° 48'	Mott, pers. comm. (1992)

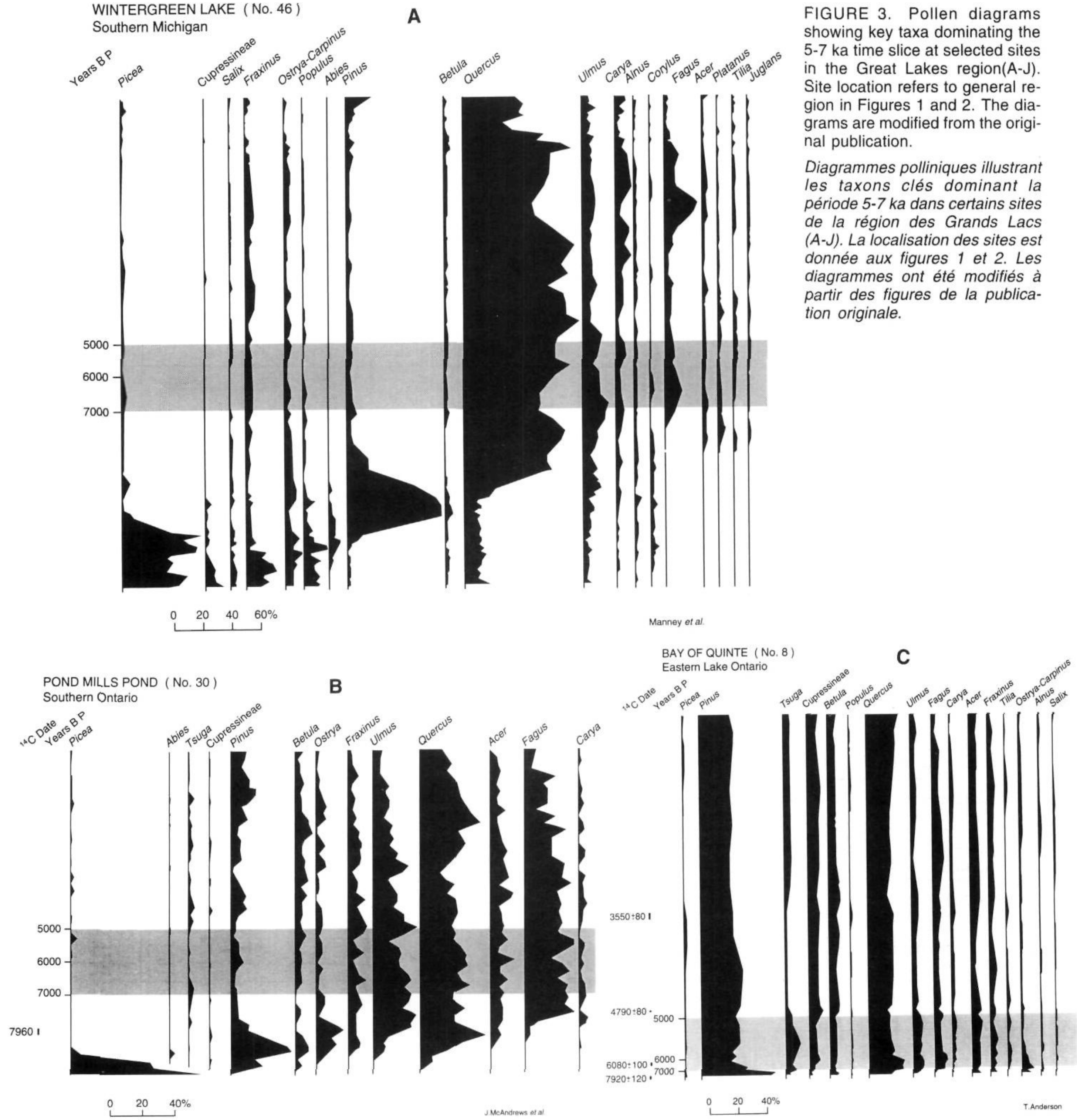
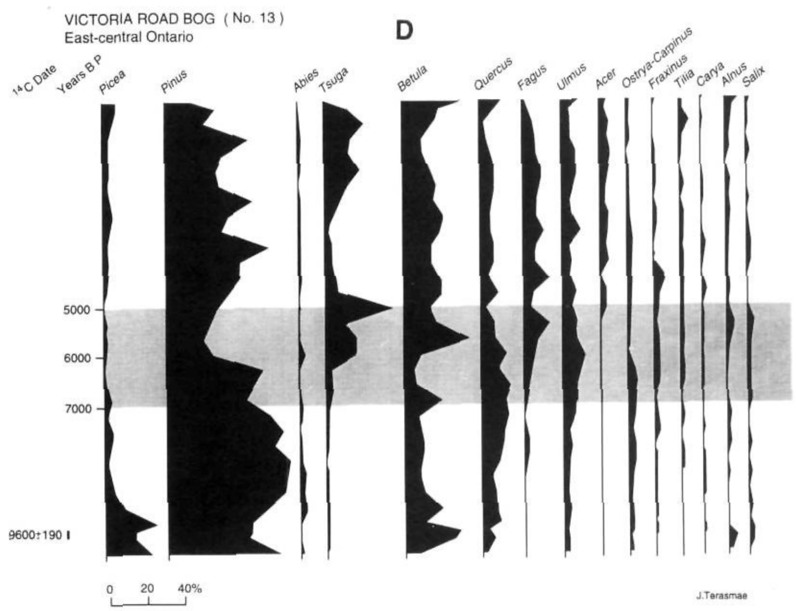


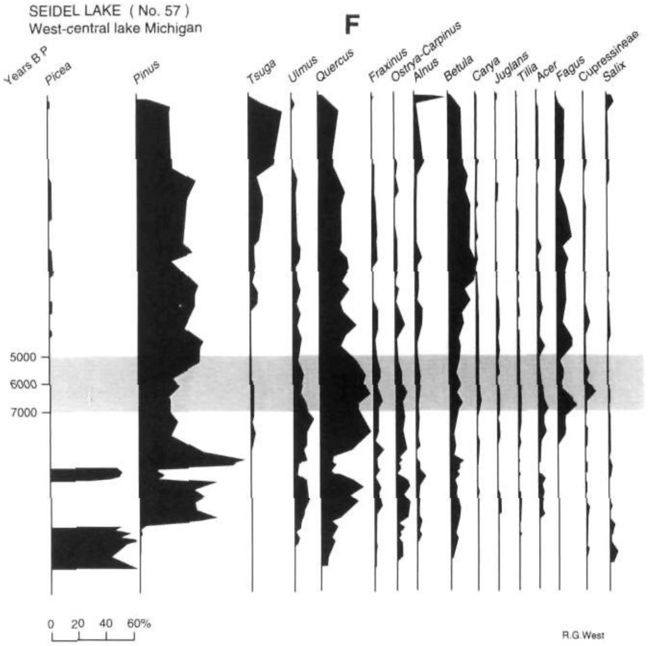
FIGURE 3. Pollen diagrams showing key taxa dominating the 5-7 ka time slice at selected sites in the Great Lakes region(A-J). Site location refers to general region in Figures 1 and 2. The diagrams are modified from the original publication.

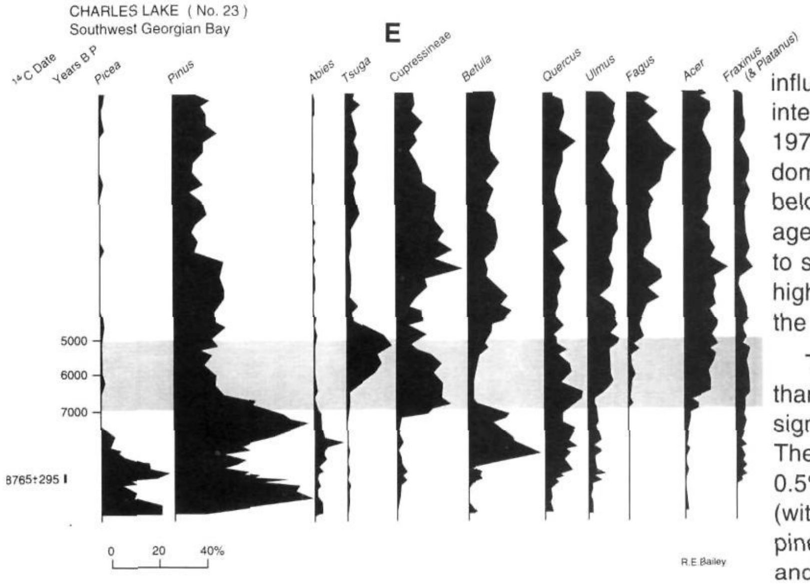
Diagrammes polliniques illustrant les taxons clés dominant la période 5-7 ka dans certains sites de la région des Grands Lacs (A-J). La localisation des sites est donnée aux figures 1 et 2. Les diagrammes ont été modifiés à partir des figures de la publication originale.

the dates are uncorrected except for those that have been adjusted for ^{13}C. The 5, 6 and 7 ka estimates were determined from the reference dates or used directly where available. Where middle Holocene dating is unavailable, and for sites located within the 5-7 ka hemlock range, the 5-7 ka time slice was derived from rates of sedimentation using the age of the first *Tsuga* increase (where available) or older dated levels and 4.8 ka for the age of the *Tsuga* decline (Davis, 1981). Where middle Holocene dating is unavailable for sites outside the hemlock range, the 5-7 ka estimates were derived using older radiocarbon dates or estimates based on pollen correlation.

Pinus strobus and Cupressineae pollen profiles were included in the database where these had been differentiated by the respective authors. The distinctions,







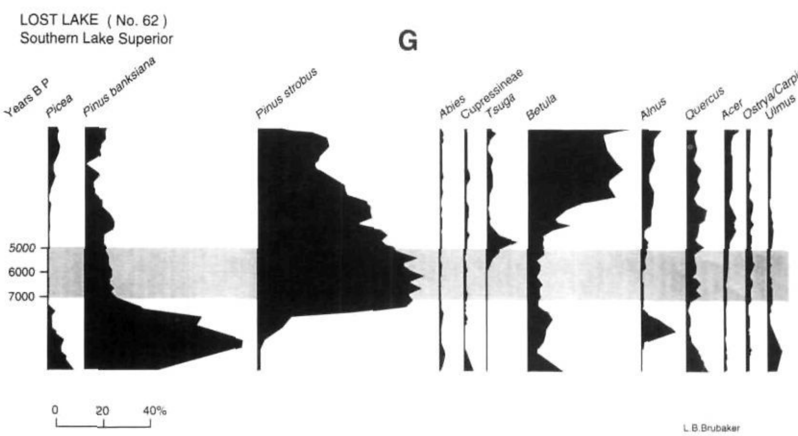
"Cupressineae" and "*Juniperus/Thuja*", in most cases refer to the juniper/cedar type pollen as it is not possible to clearly differentiate the two on morphological grounds using ordinary light microscopy. Liu (1990) uses macrofossil evidence to confirm his "*Juniperus/Thuja*" designation and inferences for cedar dominance during the middle Holocene and argues that the "*Juniperus*" (juniper) identifications by other authors were more than likely "*Thuja*" (cedar) on the basis of synchroneity of the pollen records and the fact that the climatic conditions of the middle Holocene would have been favourable for widespread cedar expansion at the same time regionally.

Isochrone lines illustrating arrival times of various tree species were determined subjectively. Since the pollen diagrams in the Great Lakes region are shown in percentage form rather than as pollen influx, I used percentage data as the basis for interpreting times of arrival. Where pollen influx data is available, in most cases it corroborates the interpretation of the percentage data (Mott and Farley-Gill, 1978; Bennett, 1987; Liu, 1990). First arrival times and dominance of a particular taxon (except for white pine, see below) were selected on each pollen profile where percentages increase steeply from background values of 0 to 5% to significant values (more than 5%) and thereafter remain high. Isochrone lines were then drawn through sites having the same dated pollen markers.

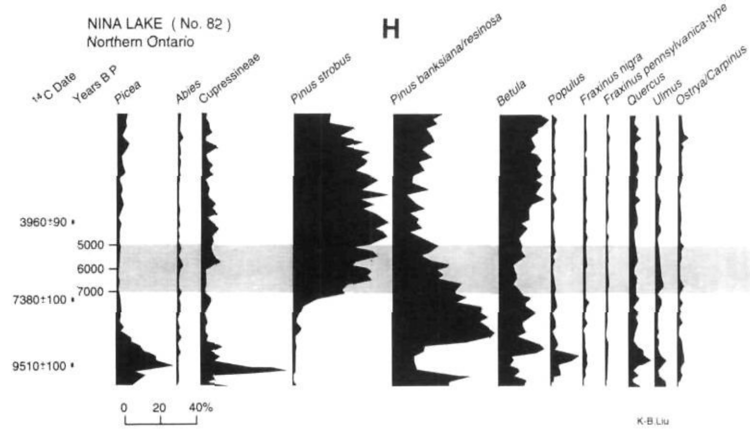
The minimum percentages of 5% are somewhat higher than the range of values that Davis *et al.* (1986) consider significant for beech and hemlock arrival and dominance. They regard percentages 1% and higher (for hemlock) and 0.5% and higher (for beech) as indicating nearby presence (within 20 km) of these tree species. In the case of white pine, I adopt the interpretations of Liu (1990) and Jackson and Whitehead (1991) who infer local presence of white pine trees based on the combined presence of white pine pollen percentages of 30-40% and greater and first occurrence of plant macrofossils (needles and seeds).

THE HOLOCENE HISTORY OF WATER LEVELS

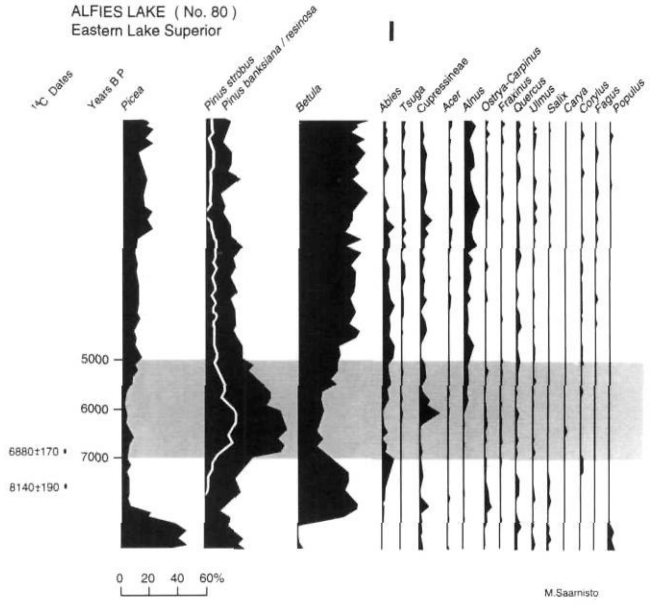
The Holocene history of water levels in the Great Lakes is documented in Anderson and Lewis (1985), Coakley and Lewis (1985), Lewis and Anderson (1989) and Lewis *et al.* (in press). An early Holocene period of reduced lake levels commenced in the Great Lakes basins following the drainage of glacial Lake Algonquin at approximately 10,500 BP (Lewis and Anderson, 1989). Lake levels rose with the eastward drainage of glacial Lake Agassiz at 9.5 ka. Supplemented by flow from glacial Lakes Barlow-Ojibway, Lake Agassiz maintained high water levels in the isostatically-depressed upper Great Lakes from 9.6-9.4 ka. Levels fell between 9.4-9.0 ka, rose again at 9 ka and remained high until shortly after 8 ka when Laurentide Ice finally retreated


LOST LAKE (No. 62)
Southern Lake Superior

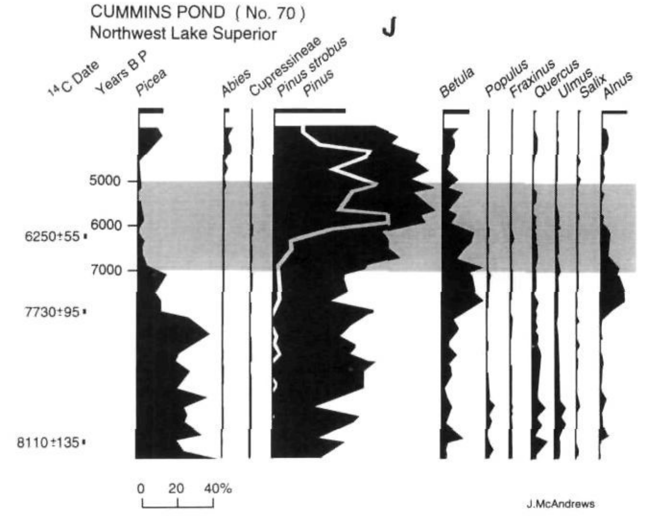
L.B.Brubaker


NINA LAKE (No. 82)
Northern Ontario

K-B Liu


ALFIES LAKE (No. 80)
Eastern Lake Superior

M.Saarnisto


CUMMINS POND (No. 70)
Northwest Lake Superior

J.McAndrews

out of Hudson Bay allowing northward diversion of meltwater to that region and the sea to inundate the Hudson and James Bay lowland (Lewis and Anderson, 1989; Lewis *et al.*, in press). In the meantime, lake levels in Erie and Ontario basins were slowly rising by local drainage from earlier postglacial low level phases. Consequently, since 7.5-8 ka, the effects from meltwater drainage would not have been a factor in the Great Lakes.

The middle Holocene (7-5 ka) history of water level change is marked by the evolution of the Nipissing Great Lakes (Figs. 4, 5, 6). By 7 ka the rising Chippewa-Nipissing lake phase had occupied the Michigan and Huron-Georgian Bay-Nipising basins and was separate from the Houghton lake phase of the Lake Superior basin. However, shortly after 7 ka but prior to 6 ka, the Houghton and Chippewa-Nipissing water planes coalesced bringing the upper Great Lakes to a common level, the Nipissing Great Lakes (Lewis and Anderson, 1989). Opposing changes had taken place in the northern and southern extremities of the Nipissing Great Lakes, *i.e.*, in the north, levels were regressing, whereas to the south, they were transgressing shoreward (Figs. 4-6) as a result of differential rebound (Lewis and Anderson, 1989).

At about 6 ka the Nipissing Great Lakes spilled southward from Lake Huron basin into Erie and Ontario basins (Anderson and Lewis, 1982; Lewis and Anderson, 1989). The inception of the Nipissing Great Lakes is recorded in offshore cores in western Lake Erie by a sediment date of 5750 ± 180 BP and sudden appearance of a distinct pollen assemblage of shallow water aquatic plants including grasses, sedges, chenopods, wood-fern, horsetail, buttonbush and pollen of other emergent and submerged aquatic plants (Lewis and Anderson, 1989). The pollen is interpreted herein as having been derived from plants that formed part of a nearshore marshy habitat that was transgressed and reworked by the Nipissing discharge into western Lake Erie at that time. The lake surface area of Erie basin was smaller at 7-5 ka than today as levels were about 5 m below present elevations (Coakley and Lewis, 1985).

The surface area of Ontario basin likewise was smaller at 7-5 ka than today and areas now inundated by Lake Ontario were land at that time. The 7-5 ka water levels in Ontario basin ranged from as much as 30 m (west basin) to 15 m (east basin) below present elevations (Anderson and Lewis, 1985). Rising lake levels over this period, however, flooded and changed the trophic state of some of the embayments of eastern Lake Ontario, *i.e.*, Bay of Quinte (site 8, Fig. 2), indicated by a change from marl to gyttja deposition dated 6 ka (Anderson and Lewis, 1985).

By 5 ka, the Nipissing transgression had reached the present shorelines and beyond in southern-most Lake Michigan and southwest Lake Superior (Fig. 6). Shortly after 5 ka, the Nipissing Great Lakes started to regress from maximum elevations with continued differential uplift of the northern Lake Huron-Georgian Bay region.

REGIONAL POLLEN STRATIGRAPHY

POLLEN STRATIGRAPHY AT 7 KA

Pollen records in and around the basins of the lower Great Lakes (Michigan, Erie, Ontario) at this time are characterized by a strong deciduous element dominated by oak and elm in the west and by changes from white pine to hemlock, beech and maple dominance in the east. Wintergreen Lake (site 46), Pond Mills Pond (site 30) and Bay of Quinte (site 8) show the west-east decrease of oak and other hardwoods compensated by the appearance of beech and more easterly by hemlock (see representative pollen diagrams, Figs. 3A, 3B, 3C). At Volo (site 42), oak reaches almost 60% and hickory increases perceptibly for the first time at 7 ka. Oak and elm percentages decrease eastwardly from 50% and 20% at Chippewa (site 49) to about 30% and 20%, respectively, at Pond Mills (site 30), to less than 10% each at van Nostrand (site 18), to less than 20% and 10%, respectively, at Barry (site 14). Decreases of oak, elm and maple in southern Ontario are compensated by increases in hemlock and beech (up to 40% and 25% hemlock and 20% and 15% beech as at sites 18 and 14, respectively). Hemlock and beech dominated most sites in the Lake Ontario basin; beech dominated sites in the northern part of Lake Erie basin.

The 7 ka records from the Lake Huron, Georgian Bay and southern Superior basins reflect for the most part maximum percentages of white pine which had displaced jack pine. Lost and Nina Lakes (Figs. 3G, 3H) show examples of the abrupt change from jack to white pine dominance. White pine percentages reach values of 65 and 60% at Lost and Mary (sites 62 and 63) and decrease easterly to about 40% as at Nina, Jack and Yelle (sites 82, 83 and 85) and 30% at Bastien (site 90). Birch either decreases from higher values during the previous jack pine dominance or is at minimum percentages during the white pine dominance. Percentages of Cupressineae (eastern white cedar) increase dramatically (0-15%) for the first time at Charles Lake (Fig. 3E).

Records from the northern Lake Superior region and areas north of the Great Lakes are dominated at 7 ka by maximum percentages of jack pine (see representative diagrams for Cummins Pond and Alfies Lake, Figs. 3H, 3I). Jack pine amounts to about 50% at Clouds and Cummins (sites 69 and 70), to about 45% at Sioux (site 74) and to about 40% at Hayes and Six (sites 73 and 84). At Alfies (site 80) jack pine amounts to 20% maximum and at the same time replaces a previous birch dominance. White pine was negligible at all these sites at this time. Birch reached values close to 20% and 25% at Cummins and Alfies, respectively (Figs. 3H, 3I).

POLLEN STRATIGRAPHY AT 6 KA

Sites of the south Michigan, Erie and Ontario basins continued to be characterized at 6 ka by high or increasing percentages of oak, elm and at some localities by maple. Oak and hickory maintained peak values at Volo (site 42) whereas at the more easterly sites such as Wintergreen Lake and Pond Mills Pond (Figs. 3A, 3B) oak and elm were dominant. Beech reached maximum at sites in southern Ontario (up to 30% at van Nostrand and Maplehurst, sites 18 and 29 and to greater than 15% at Barry, site 14) and was becoming established in southeast Michigan (14% and 10% maximum at Frains and Chippewa (sites 47 and 49), respectively.

At 6 ka the Lake Huron and Georgian Bay basins were transitional between high or increasing percentages of hemlock in the south (Victoria Road Bog and Charles Lake representative diagrams, Figs. 3D and 3E) and maximum percentages of white pine in the north indicated by the Nina Lake diagram (Fig. 3H). Hemlock increased at the expense of white pine from about 1% or less to about 15% and 30%, at Victoria Road Bog and Nutt Lake (sites 13 and 12), respectively, from 7 to 6 ka. Beech accompanied the northward migration of hemlock as beech increased from 0 to 5% at Victoria Road since 7 ka. At the same time, a tongue of high birch percentages characterized east-central Ontario (values were close to 25% at MacKay, site 3, but less towards the tip of the tongue). Significant at sites in the Georgian Bay basin and areas northward were high or increasing percentages of Cupressineae pollen commencing at or just after 6 ka (see representative diagrams for Charles, Nina and Alfies lakes (Figs. 3E, 3H, 3I). Cupressineae increased to 5-10% at Jack and Six Lakes (sites 83 and 84), to 15% at Alfies Lake (Fig. 3I) and to 35% at Yelle (site 85).

Sites of the Lake Superior basin show a dramatic increase in percentages of white pine at the expense of jack pine and, at some sites, at the expense of birch during the 7-6 ka period (see representative diagrams for Alfies Lake and Cummins Pond, Figs. 3I and 3J). White pine increased 2-fold at Myrtle (site 68), at least 3-fold at Jacobson and Clouds (sites 65 and 69), 7-fold at Sioux (site 74) and up to 8-fold at Cummins (site 70).

POLLEN STRATIGRAPHY AT 5 KA

Records from Wintergreen Lake, Pond Mills Pond and Bay of Quinte (Figs. 3A, 3B, 3C) show that the 5 ka record of the lower Great Lakes region had not changed from that at 6 ka. Oak, elm and hickory continued to dominate in the western part of the region whereas oak, elm, beech and maple were prominent in the east. However at other distant sites pollen changes were evident. Beech percentages increased from those at 6 ka at sites in the Michigan and Huron basins. Ontario basin sites dominated by hemlock show enhanced percentages of hemlock (up to 25% and 65% at Barry and Belmont, respectively, sites 14 and 16).

The Lake Huron and Georgian Bay basins at 5 ka, like that at 6 ka, were transitional between a hemlock-dominated stratigraphy in the south (Victoria Road Bog and Charles Lake diagrams, Figs. 3D, 3E) and a white pine-dominated stratigraphy to the north (Nina Lake diagram, Fig. 3H). However, by this time the hemlock and beech domination had progressed slightly northward and birch was increasing southward. Hemlock increased about 3 and 10-fold at Victoria Road and Found (sites 13 and 11), respectively, over the 6-5 ka period. Birch increased almost 2-fold at Jack (site 83), 3-fold at Nutt (site 12) and to 8-fold at Found (site 11). Percentages of Cupressineae decreased at sites near Georgian Bay, *i.e.* Charles Lake (Fig. 3E) but increased at others distant from the Bay, *i.e.* Nina Lake (Fig. 3H). Significant increases of Cupressineae were recorded for the first time at 5 ka at Weslemkoon and Found (sites 10 and 11).

The 5 ka pollen stratigraphy of the northern Michigan and Superior basins differed in some respects from that at 6 and 7 ka. White pine percentages remained high in the Superior basin but increased at sites south of Lake Superior (almost 2-fold at Seidel Lake, Fig. 3F). Birch essentially remained unchanged since 6 ka in western Superior region (Cummins Pond, Fig. 3J) but became more prevalent in eastern Superior region, *i.e.* at Nina and Alfies lakes (Figs. 3H, 3I). Cupressineae decreased 2-fold at Hayes (site 73) since 7 ka.

INFERRED FOREST COMPOSITION

FOREST COMPOSITION AT 7 KA (FIG. 4)

By 7 ka, a deciduous forest comprising mainly oak, elm, hickory, with scattered maple, basswood and birch was well established in the watersheds of the Erie and south Michigan basins. To the east, however, hemlock and beech had moved into and enclosed the Ontario basin. Thus a mixed forest dominated by hemlock and beech had replaced white pine almost everywhere in the Huron-Ontario interlake region and beech extended west to the Michigan basin (Figs. 4A, 4B). Outliers of the main hemlock migrational front may have existed in southern and northern Michigan (Davis *et al.*, 1986).

At the same time, white pine dominated the forest of the upper Great Lakes region from Québec to and including the southern half of Superior basin. White pine expanded north to the Clay Belt (Figs. 1 and 4A) beyond its present-day range in northeastern Ontario and western Québec (Terasmae and Anderson, 1970). It replaced large expanses of jack pine which covered most of this area along with birch and spruce. The northern limit of white pine almost coincided with the southern limit of birch (Fig. 4). By this time small populations of Cupressineae would have been restricted to dry habitats above the rising Chippewa-Nipissing shoreline on Manitoulin Island and southern Bruce Peninsula (Figs. 1 and 4).

FOREST COMPOSITION AT 6 KA (FIG. 5)

By 6 ka there were dramatic changes in the composition of the forests and movement of certain forest taxa in the Great Lakes region (Figs. 5A, 5B). Beech expanded to the north and west where it invaded the oak-hickory-dominated forests of the Michigan basin; outlier populations had reached the west side of Lake Michigan. Hemlock expanded its 7 ka range west and northwest to its outlier populations in southern and northern Michigan and northward into east-central Ontario and Ottawa Valley. At the same time, birch had

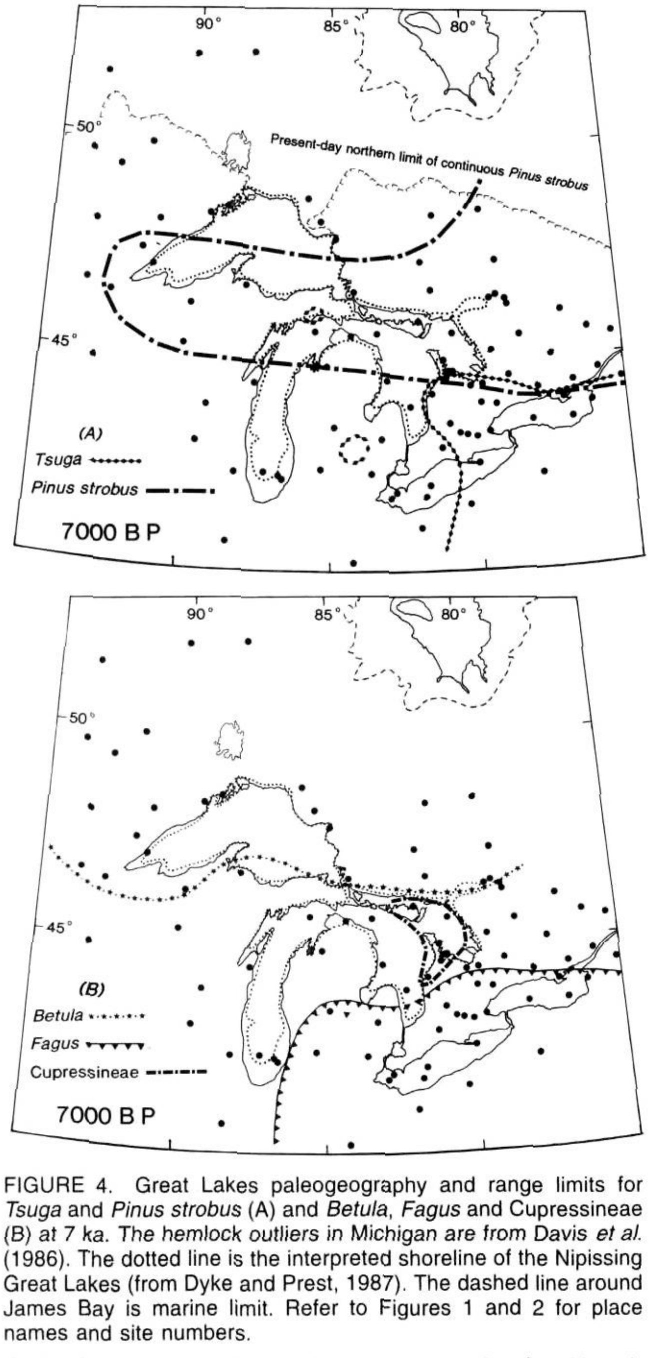


FIGURE 4. Great Lakes paleogeography and range limits for *Tsuga* and *Pinus strobus* (A) and *Betula*, *Fagus* and Cupressineae (B) at 7 ka. The hemlock outliers in Michigan are from Davis *et al.* (1986). The dotted line is the interpreted shoreline of the Nipissing Great Lakes (from Dyke and Prest, 1987). The dashed line around James Bay is marine limit. Refer to Figures 1 and 2 for place names and site numbers.

Paléogéographie des Grands Lacs et limites de répartition de Tsuga *et de* Pinus strobus *(A) ainsi que de* Betula, Fagus *et Cupressineae (B) à 7 ka. L'ensemble isolé de pruches au Michigan provient de Davis* et al. *(1986). La ligne pointillée représente le littoral probable des Grands Lacs Nipissing (de Dyke et Prest, 1987). Le tireté autour de la baie de James est une limite marine. Les figures 1 et 2 donnent la toponymie et la numérotation des sites.*

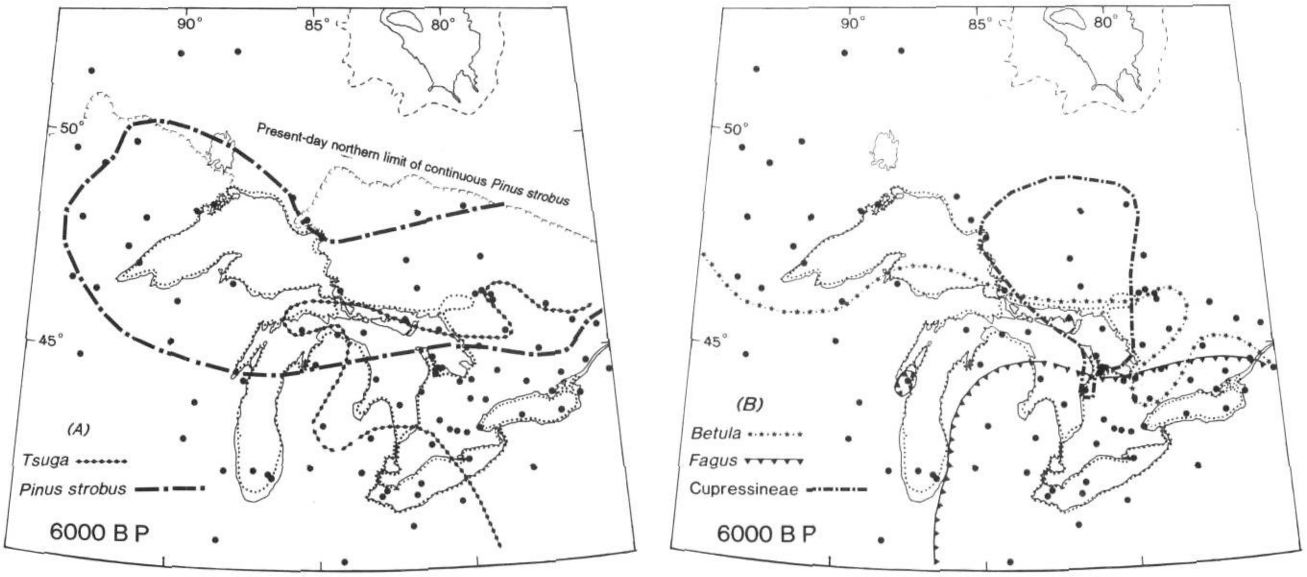


FIGURE 5. Great Lakes paleogeography and range limits for *Tsuga* and *Pinus strobus* (A) and *Betula, Fagus* and Cupressineae (B) at 6 ka. The dotted line is the interpreted shoreline of the Nipissing Great Lakes (upper Great Lakes basins) from Dyke and Prest (1987) and southward extension into Erie and Ontario basins.

Paléogéographie des Grands Lacs et limites de répartition de Tsuga *et de* Pinus strobus *(A) ainsi que de* Betula, Fagus *et Cupressineae (B) à 6 ka. La ligne pointillée représente le littoral probable des Grands Lacs Nipissing (bassins supérieurs des Grands Lacs) (de Dyke et Prest, 1987) et extension vers le sud dans les bassins des lacs Ontario et Érié.*

entered east-central Ontario in tongue-like fashion from southern Québec at the expense of white pine.

The 6 ka forest of the upper Great Lakes watershed was dominated almost everywhere by white pine. White pine had encroached on and severely reduced populations of jack pine and spruce in the northern Lake Huron-Georgian Bay and Superior basins. It expanded to approximately its present-day northern limit (Fig. 5A). The birch distribution essentially remained unchanged from 7 ka. Cupressineae, on the other hand, increased its range several times since 7 ka with a major expansion into the region north of Lake Huron and Georgian Bay.

FOREST COMPOSITION AT 5 KA (FIG. 6)

An oak-hickory forest remained prominent throughout the Erie and Michigan basins. Beech continued to be an important component of that forest and of the hemlock-dominated mixed forest of the Ontario and Georgian Bay basins as it expanded slightly further to the north and northwest (Fig. 6B). Hemlock expanded to the northwest into upper Michigan peninsula, further up the Ottawa Valley, and slightly beyond its present-day southern limit in southern Michigan (Fig. 6A).

White pine remained at its present-day limit in the northern Lake Huron-Georgian Bay region (Fig. 6A) but advanced southwesterly into the deciduous forest indicated in the Seidel Lake diagram (Fig. 3F) by the replacement of oak, elm and other hardwoods by pine, most likely, white pine. The birch migration out of the northeast had penetrated more deeply into the white pine-dominated forest of the Georgian Bay basin. Cupressineae maintained its 6 ka range even though it decreased in some areas and increased in others.

THE 5-7 KA FOREST ECOTONES

Using discriminant analysis, Liu (1990) has shown that the boreal forest/Great Lakes-St. Lawrence forest (mixed forest of this study) ecotone had advanced as much as 140 km north of its present position at 6 ka. Liu attributes the northward expansion of the ecotone to the effect of a warmer and drier climate in the northern Great Lakes region. Middle Holocene temperatures of 1°C to 2°C above modern values are suggested for this region (McAndrews, 1981).

In this study, changes in the position of the 5-7 ka deciduous-mixed forest ecotone were examined by comparing modern pollen percentages from the present-day Deciduous-Mixed Forest ecotone with 5-7 ka pollen percentages at sites north of the ecotone. Good comparisons exist between the present-day pollen percentages at Henderson (site 6) and Disterhaft (site 59) situated within the ecotone and the 5-7 ka pollen percentages at Lambs Pond (site 4) and Seidel Lake (site 57), respectively located just north of the ecotone (Figs. 2, 7). The data correspondence suggests that the 5-7 ka deciduous-mixed forest ecotone may have been displaced northward by as much as 60-70 km (Fig. 8). The differences in the deciduous-mixed and mixed-boreal ecotonal displacements suggest that the warmer and drier climate at 5-7 ka was probably more pronounced and had a greater effect on forest changes and species migration in the northern Great Lakes region than in the south.

DISCUSSION

The middle Holocene forest history of the Great Lakes region may be tied to regional climate changes and events relating to the evolution of the Great Lakes. Influences from

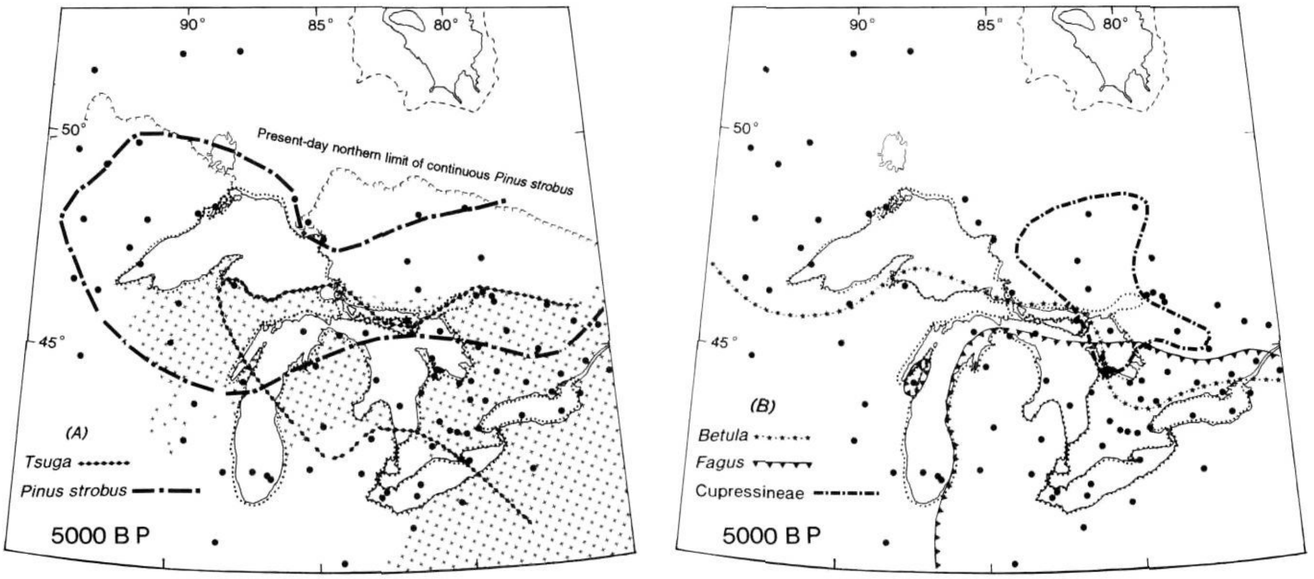


FIGURE 6. Great Lakes paleogeography and range limits for *Tsuga* and *Pinus strobus* (A) and *Betula*, *Fagus* and Cupressineae (B) at 5 Ka. Pattern denotes the present-day range of *Tsuga canadensis* (eastern hemlock). The dotted line is the interpreted shoreline of the Nipissing Great Lakes (upper Great Lakes basins) from Dyke and Prest (1987) and southward extension into Erie and Ontario basins.

Paléogéographie des Grands Lacs et limites de répartition de Tsuga *et de* Pinus strobus *(A) ainsi que de* Betula, Fagus *et Cupressineae (B) à 5 ka. La trame donne la répartition actuelle de la pruche du Canada (*Tsuga canadensis*). La ligne pointillée représente le littoral probable des Grands Lacs Nipissing (bassins supérieurs des Grands Lacs) (de Dyke et Prest, 1987) et extension vers le sud dans les bassins des lacs Ontario et Érié.*

deglacial drainage changes of the upper Great Lakes region (Anderson and Lewis, 1992) and the effect of large-area water bodies such as the Nipissing Great Lakes would have impacted on climate. Long-term changes in climate in combination with topography, soil drainage conditions, presence of new land bridges exposed through differential uplift, fire activity, dispersal and competitive factors influenced migrations of tree populations and contributed to the progressive development of the forests of the Great Lakes region.

Hydrological changes commencing with the retreat of Laurentide Ice, recession of glacial lakes Agassiz and Ojibway to Hudson Bay and subsequent onset of the Nipissing Great Lakes affected much of the Great Lakes region shortly after 8 ka. Superimposed on these hydrological changes was enhanced regional warming. July mean temperatures had increased between 1° and 2°C nearly everywhere in the Great Lakes region between 9 and 6 ka (Bartlein and Webb, 1985; McAndrews and Campbell, 1993; Bartlein *et al.*, 1984). The climate at this time favoured northward migrations of oak, elm, beech, maple, hickory and basswood into the Great Lakes basin for the first time (Webb, 1981; Webb *et al.*, 1983). Eastward advancement of the prairie-forest ecotone (Davis, 1977; Webb *et al.*, 1983) signaled marked climatic gradients between 7 and 5 ka when the Holocene climate was at its driest and warmest. The combined hydrological and climate changes undoubtedly altered the climatic system of the Great Lakes region. The altered climate may have caused or contributed to a change in the "growth" environment which, in turn, initiated forest change in the Great Lakes region. Changes in the "growth" environment are seen as an important factor that can induce population change (Dexter *et al.*, 1987).

Like Lake Superior today (Phillips, 1978), the cold-deep, large-area Nipissing Great Lakes would have acted as a vast reservoir for the storage of heat energy absorbed from the overlying air masses. Consequently, and like Lake Superior today, the Nipissing Great Lakes would have exerted a cooling effect on the immediate shoreline. Because of their larger surface area, this climate effect would have been felt throughout the entire Great Lakes region. Westerly air masses crossing the cold surface waters of the Nipissing Great Lakes meeting the warm air masses (that dominated the Great Lakes region at 5-7 ka) would have induced humid-cool conditions over and in the lee areas of this lake phase. These conditions may have provided an optimum "growth" environment or local microclimate for hemlock and beech expansion, in particular, and possibly explain their migration routes into the upper Great Lakes region between 7 and 5 ka (Figs. 4-6). By 7 ka the advancing fronts of the hemlock and beech migrations were at or near the shores of the Nipissing Great Lakes. By 6 ka hemlock and beech reached dominant status in the forest community and expanded their populations to the north, west and northwest towards the centre of the Nipissing Great Lakes. Hemlock followed the topographic lowlands of the Ottawa Valley and the Huron-Michigan interlake area. Hemlock and beech continued to expand to the west and northwest and by 5 ka their major population expansion centres coincided with the centre of the Nipissing Great Lakes influence. The 5 ka range extension of hemlock beyond its present-day limit in southern Michigan suggests perhaps some southward movement because of lake effect. Within the 7-5 ka interval, beech and hemlock thus migrated in a northwesterly direction at rates of about 160 and 280 m yr^{-1}, respectively, which fall within the maximum

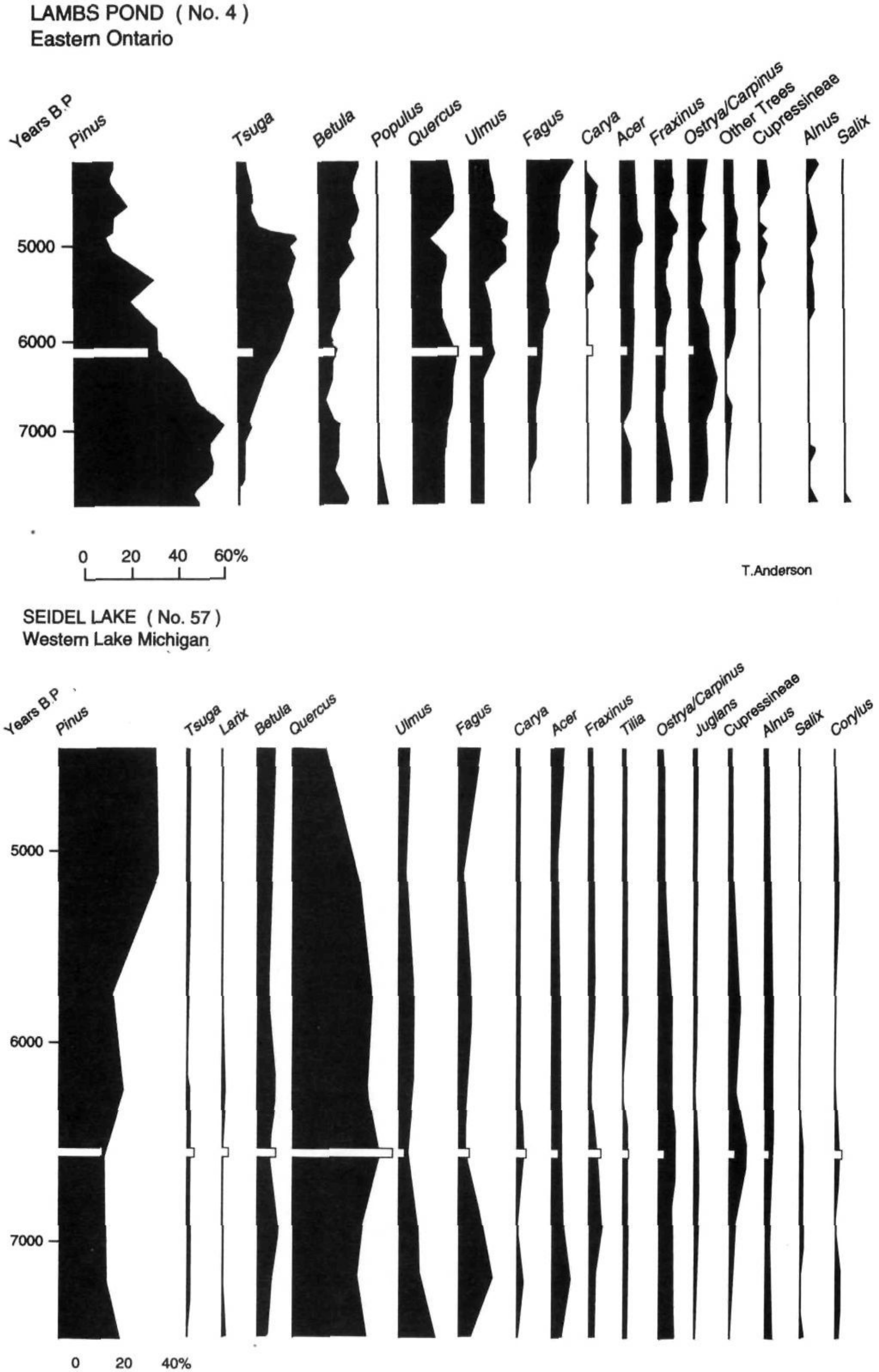


FIGURE 7. Modern pollen percentages at Henderson Harbour (site 6) and Disterhaft Farm Bog (site 59) superimposed (white bar) on 5-7 ka pollen percentages at Lambs Pond (A) and Seidel Lake (B), sites 4 and 57, respectively.

Pourcentages polliniques actuels de Henderson Harbour (site n° 6) et de Disterhaft Farm Bog (site 59) surimposés (bande blanche) sur les diagrammes polliniques de Lambs Pond (A) et Seidel Lake (B).

range of 150-300 m yr^{-1} suggested for beech in Europe and North America (Huntley and Webb, 1989).

SOUTHERN GREAT LAKES REGION

Evidence at several basin sites in the southern Great Lakes region indicate that there may have been a correlation between lake-infilling, hydrological changes and climate within the period 7-5 ka. Basins were occupied by a lake environment with marl or gyttja deposition but bog/marsh conditions encroached into the open-water areas and the lakes were reduced in size and some transformed to peat bogs with peat deposition. In southern Ontario, lake infilling occurred as early as 7 ka (Anderson, 1982; Warner and Kubiw, 1988) to shortly after 5 ka (Anderson, 1971).

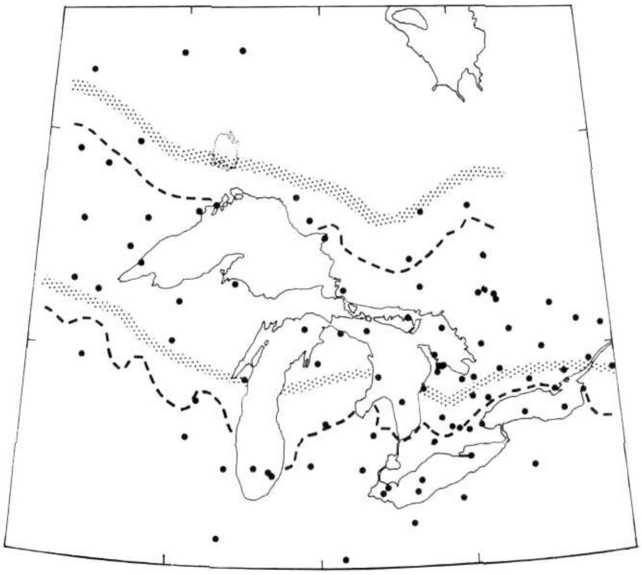


FIGURE 8. Present-day Deciduous-Mixed and Mixed-Boreal Forest ecotones (dashed lines) and corresponding inferred 5-7 ka ecotones (stippled band), Great Lakes region. Refer to Figures 1 and 2 for place names and site numbers.

Écotones actuels des forêts de feuillus et mixtes et des forêts mixtes et boréales (tiretés) et écotones probables à 6 ka (trame pointillée). Les figures 1 et 2 donnent la toponymie et la numérotation des sites.

Lake infilling was similarily underway shortly after 5 ka at Chippewa Bog (site 49) in southern Michigan (Bailey and Ahearn, 1981). Lakeward bog encroachment and lake-infilling coincided with and was likely affected by the regionally warmer and drier climate evident by 7 ka. The warmer and drier climate undoubtedly caused a reduction in regional groundwater levels and local water tables which enhanced the bog encroachment and lake-infilling processes. Webb *et al.* (1993) show evidence that all lakes throughout eastern North America had lower water levels at 6 ka than at any time previous to and since 6 ka.

Some sites located east and inland from Lake Huron apparently had completely dried up during the early to middle Holocene period of maximum warmth and dryness. For example, at Ellice Bog (site 28, Fig. 2, Table I) the 8-4 ka period which encompasses the entire pine-dominated period and first hemlock pollen maximum is missing. Peat deposition apparently slowed down or ceased entirely in the bog at this time (Anderson *et al.*, 1989). Furthermore, pollen percentages of Cyperaceae (sedges) decline whereas those of Ericaceae (heaths) increase across the hiatus interval implying a significantly lowered water table and drier bog surface corresponding with the timing of the sediment and pollen hiatus. A similar sediment hiatus is documented between marl and gyttja deposition in cores from Rice Lake, Ontario (Yu and McAndrews, 1994), indicated in Figure 1. Yu and McAndrews attribute the hiatus, which lasted some 3000 years, to a period of low-water levels caused by a warm-dry climate between 6000 and 3000 years BP.

Lower base levels of southwardly discharging rivers and streams at 7-5 ka than today possibly contributed to the basin hydrological changes and in-filling processes that affected some sites of the southern Great Lakes region. These sites were, as they are now, at the headwaters of rivers and streams that drained south to Erie and Ontario basins. Because Erie and Ontario basin levels were generally low at 7-5 ka or were rising from previous low stages (Coakley and Lewis, 1985; Anderson and Lewis, 1985), the base levels of these rivers and streams may also have been lower at 7-5 ka than today resulting possibly in steeper downslope discharge and hence greater groundwater withdrawal from upstream watersheds during the period of maximum warmth.

NORTHERN GREAT LAKES REGION

The succession of forests of the northern Great Lakes region was influenced by the presence and disappearance of glacial lakes Barlow and Ojibway. These large-area glacial lakes not only provided a physical barrier to migration of trees to this region but the lakes acted as a heat sink and thus had the effect of maintaining a cold climate over much of the area until after 8 ka. Once the cold large-area glacial lakes had drained to Hudson Bay (Lewis *et al.*, in press), the initial vegetation to colonize the area was forest; spruce, jack pine and birch were co-dominants of that forest (Richard, 1979, 1980; Liu, 1990). By 7 ka white pine had replaced jack pine in the Clay Belt area (Fig. 1) of northern Ontario and western Québec. It migrated very quickly into this area from the south, most likely by way of the topographic lowland northeast of Georgian Bay (Fig. 2) which Hills (1962) refers to as the "migration channel" for northerly species migrations.

The middle Holocene warm climate may have been indirectly responsible through fire history in bringing about the proliferation of first jack pine and later white pine in the northern Great Lakes region. Fire can be more common in drier conditions; so therefore will pine, and once established, a pine-dominated forest because of its high combustibility can often increase the probability of fire. Lost Lake, Nina Lake and Cummins Pond (Figs. 3G, 3H, 3J), Lac Bastien (site 89) (Bennett, 1987) and Upper Mallot Lake (McAndrews and Campbell, 1993) indicate brief birch and alder expansions prior to the domination of white pine implying fire activity during the earlier jack pine period. White birch and alder are known to reproduce vegetatively and grow more rapidly than other trees such as white pine immediately after a fire (Swain, 1973). Thus fire may have favoured the natural regeneration of birch and alder and possibly explain the southwesterly migration of birch into Georgian Bay basin which was clearly evident by 6 ka.

Synchronous with the southwesterly movement of birch was the northern expansion of Cupressineae into the northern Lake Huron-Georgian Bay region. On the basis of prominent middle Holocene pollen and macrofossil evidence, Liu (1990) maintains that eastern white cedar proliferated in the northern Lake Huron-Georgian Bay region in response to the shift to a warmer and drier climate which at 6 ka reached maximum proportions in this region. The lower present-day mean annual precipitation in this region relative to the immediate areas to the west, south and east (Chapman and

Thomas, 1968) suggests even drier conditions prevailed at 6 ka which may have favoured the expansion of eastern white cedar northward to the Clay Belt; like white pine, eastern white cedar likely expanded there via the northern Ontario "migration channel".

Eastern white cedar grows best on neutral or alkaline soils of limestone origin (Fowells, 1990). Dredge and Cowan (1989) have shown that the tills of northern Ontario (Precambrian Shield terrain and Hudson Bay Lowlands) have high carbonate contents (35% by weight and a range of 9-52%) that reach up to 30% within the 6 and 5 ka ranges of eastern white cedar. The middle Holocene distribution of eastern white cedar may therefore be a result of a combination of optimal climatic and substrate conditions which co-existed in the upper Great Lakes region at that time.

Sites situated in or just below the present-day Boreal-Mixed Forest ecotone (Fig. 2) show evidence that the ecotone started to move south immediately following the climatic optimum. Significant increases in spruce commence as early as 5 ka at Ring and Alfies (sites 78 and 80). Other sites, *i.e.*, Nina and Jack (sites 82 and 83) in the east and at Clouds, Cummins and Hayes (sites 69, 70, 73) in the west show up to 2-fold increases in both percentage and influx of spruce pollen dominance at or shortly after 4 ka. The increase in spruce represents an increase in the frequency of spruce trees and reflects a southward shift of the spruce ecotone in response to post-5 ka cooling (Anderson *et al.*, 1989; Liu, 1990).

SUMMARY AND CONCLUSIONS

Beech migrated into and became established in the Michigan and Erie basins by 7 ka at the expense of the deciduous trees, oak, elm, hickory and basswood; at the same time hemlock and beech replaced white pine in the Erie-Ontario region. By 6 ka both hemlock and beech had expanded their ranges markedly to the west and north. Hemlock replaced white pine in the Georgian Bay watershed and Ottawa Valley. Tree species that had already been there showed some north and south movement. For example, white pine and eastern white cedar migrated northward and invaded a boreal-type forest while birch moved south and southwest into the white pine-dominated forest. Notable migrational strides by 5 ka included white pine expanding slightly southwesterly into a previously established deciduous forest, beech and hemlock advancing further west and north and birch moving more southwesterly into the Huron-Georgian Bay watershed.

The 7-5 ka forest changes coincided with marked changes in regional climate. Regional climatic warming modulated by a lake effect from the Nipissing Great Lakes may have induced a suitable "growth" environment which favoured migration of individual forest species, hemlock and beech in particular. The lake effect may have provided the stimulus for the hemlock and beech invasions of the white pine-dominated forests by 7 ka and subsequent range expansions to the west and northwest by 6 and 5 ka. Regional warming until 5 ka allowed white pine and eastern white cedar to expand their ranges northward into a jack pine-dominated boreal forest and white pine southwesterly into the deciduous forest. Northward displacement of the boreal-mixed forest ecotone (by as much as 140 km) and the mixed-deciduous forest ecotone (by about 60-70 km) occurred in response to the warm-dry regional climate which dominated the Great Lakes region at 6000 years ago.

Like the present-day upper Great Lakes (*i.e.,* Lake Superior), the Nipissing Great Lakes impacted on the climate and vegetation of central Canada by exerting a moderating (cooling) effect on the nearby land areas and in the lee areas inland from the lakes. The 6 ka climate and paleogeography of the upper Great Lakes may therefore be considered analogous with the present upper Great Lakes in a global warming context.

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