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TWO LATE QUATERNARY POLLEN PROFILES FROM GATINEAU PARK, QUEBEC

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TWO LATE QUATERNARY POLLEN PROFILES FROM GATINEAU PARK, QUEBEC

Abstract

Two pollen diagrams, one from the eastern end and one from the western end of Gatineau Park, Quebec, illustrate the vegetational changes that have occurred over the last 11 000 years or so in that area. Tundra conditions and shrub tundra conditions followed deglaciation and emergence of part of the area from beneath the Champlain Sea. Poplar and/or aspen were the first trees to invade the area about 10 700 years ago, but occurred only as clumps or groves growing on suitable sites of the generally open landscape. Spruce trees replaced poplar and/or aspen about 500 years later but did not form closed forests. The incursion of white birch and jack and/or red pine along with smaller amounts of other hardwoods heralded the closing of the forest. White pine soon became plentiful and hardwoods continued to increase. Hemlock became prominent at the expense of the pines about 6500 years ago. The beech/maple forests that prevailed at the time of settlement were in existence by 2200 years B.P., and only minor changes occurred in response to various environmental factors. Logging and agriculture have greatly altered the forests during the last 180 years.

Résumé

Deux diagrammes polliniques, l'un provenant de l'extrémité est du parc Gatineau (Québec) l'autre de l'extrémité ouest, illustrent les changements qu'a connus la florule de cette région depuis 11 000 ans environ. Après la fonte des glaciers, lorsque les eaux de la mer de Champlain se sont retirées d'une partie de la région, la toundra et la toundra arbustive y ont fait leur apparition. Le peuplier et(ou) le tremble ont été les premiers arbres à s'implanter, il y a quelque 10 700 ans, mais ils ne poussaient qu'en bosquets, aux endroits les plus favorables, au milieu d'un paysage presque sans arbres. Quelque 500 ans plus tard, l'épinette a remplacé le peuplier et(ou) le tremble sans toutefois former de forêts denses. Le bouleau blanc, le pin gris et(ou) le pin rouge, ainsi que quelques autres feuillus ont constitué les premières forêts denses. Bientôt le pin blanc devint abondant, tandis que les feuillus continuaient d'augmenter. La pruche a pris le dessus sur les pins il y a 6500 ans environ. La forêt de hêtres et d'érables qui couvrait la région aux temps de la colonisation s'y trouvait déjà il y a 2200 B.P.; durant cette période, seuls quelques changements mineurs se sont produits sous l'action des facteurs du milieu. Depuis 180 ans, la coupe du bois et l'agriculture ont considérablement modifié les forêts.

INTRODUCTION

The rate of northward migration of vegetation following retreat of Wisconsin glacial ice was dependent on many factors including climate, soil formation, pioneering ability, provenance, and geography. Various types of geographical barriers probably played a prominent role, not the least of which were large bodies of water. The Champlain Sea was one such large expanse that extended up St. Lawrence River valley almost to the Great Lakes and up Ottawa River valley beyond Pembroke, Ontario, forming a barrier to migration of plants onto the southeastern part of the Canadian Shield. Although continually decreasing in size and extent due to the emergence of the land because of isostatic rebound, the Sea occupied upper St. Lawrence and lower Ottawa valleys from about 12 800 to about 10 000 radiocarbon years ago (Richard, 1975).

Early palynological work in the Ottawa region by Potzger and Courtemanche (1956a, b) included studies of peat bogs from Gatineau Valley to the north and Ottawa Valley to the east but these were incomplete and lacked radiocarbon control. Several sites in the Ottawa area were studied by Mott and Camfield (1969) and Camfield (1969); but these are at low elevations and postdate the Champlain Sea and channelling of the ancestral Ottawa River, making them relatively young and lacking the early vegetation record.

Ramsay and Pink lakes are situated just north of Ottawa in Gatineau Park (Fig. 1) which formed the northern shore of the Champlain Sea. Ramsay Lake basin was at or just above the limit of the sea, whereas the Pink Lake basin was inundated by the sea in its early stages. Both lakes record the early vegetational history of the southeastern edge of the Canadian Shield, as well as the changes that have occurred to the present.

Description of Sites

Pink Lake (45°28'10"N, 75°48'30"W) is located 8 km northwest of Hull, Quebec near the eastern end of Gatineau Park, a National Capital Commission park in the Gatineau Hills north of Ottawa (Fig. 1). The small (9 ha) lake occupies a bedrock basin in crystalline limestone of Precambrian age along the southern boundary of the Canadian Shield. The catchment area is about 95 ha. One small stream flows into the lake from a boggy area to the north, and the lake drains to the east to Gatineau River. The lake surface is about 162 m a.s.l. The landscape surrounding the lake is rugged with local relief up to 30 m and supports a mixed hardwood forest dominated by beech and maple.

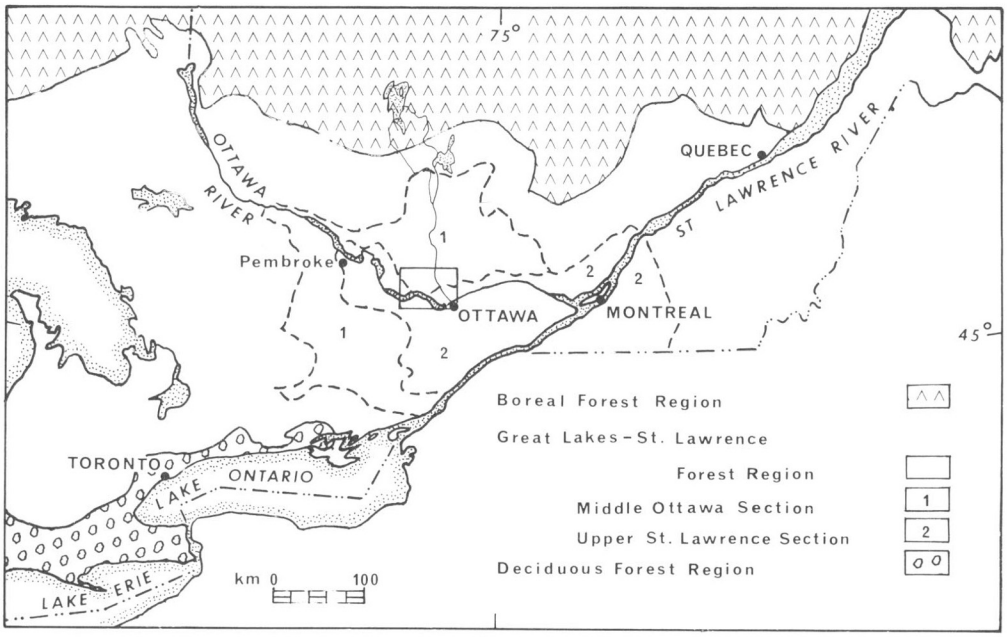

Figure 1a. *Location map showing study area and major forest regions and sections.*

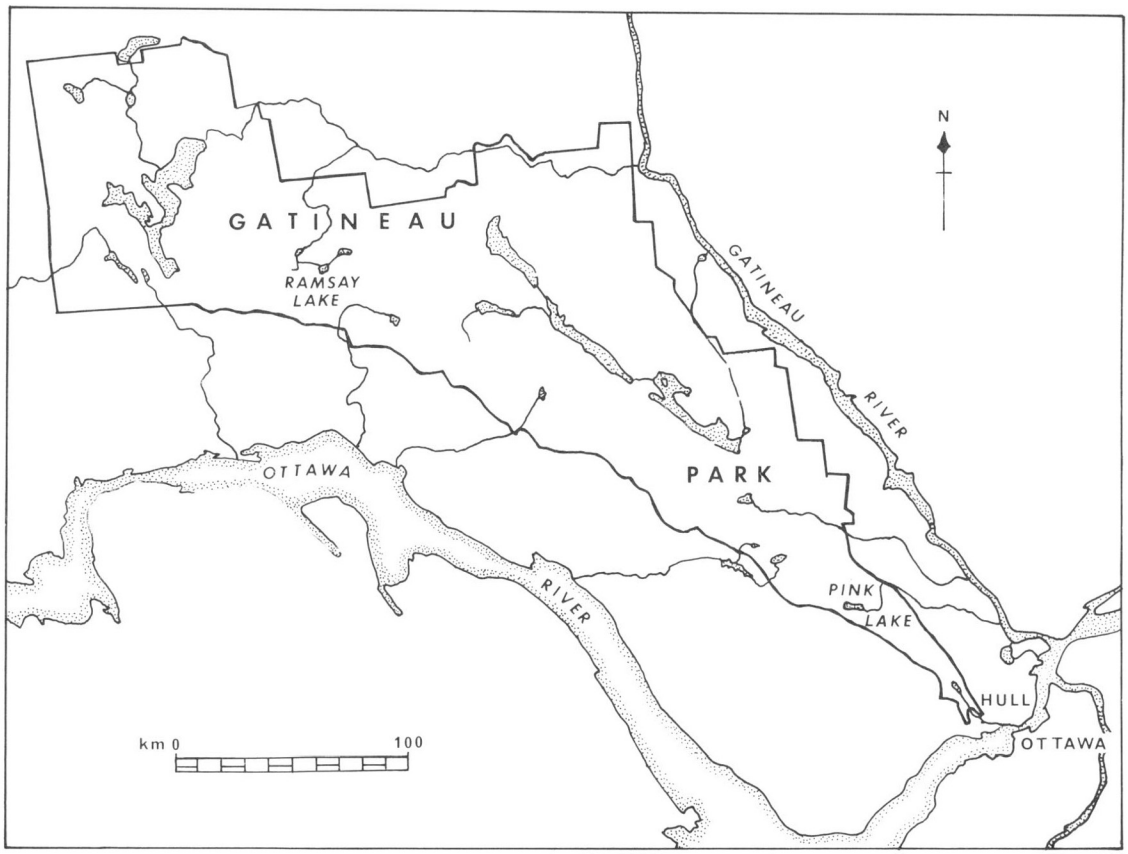

Figure 1b. *Detailed map of Gatineau Park showing location of lake sites.*

The local relief is reflected in the lake basin itself which has a maximum water depth of 20 m. Relatively little shallow water is available for the growth of aquatic plants (Aiken and Gillett, 1974). Because of the surrounding limestone bedrock, the water is alkaline and carbonates are precipitated in shallow water during the summer months. Pink Lake is a meromictic lake and is depleted in oxygen in the monimolimnion throughout the year (Dickman et al., 1975; Dickman, 1979).

Ramsay Lake (45°36'00"N, 76°06'00"W) is about 29 km northwest of Pink Lake towards the western limit of Gatineau Park (Fig. 1). The lake lies at 200 m a.s.l., covers an area of about 9 ha, and occupies a depression bordered by bedrock and glaciofluvial deposits. The lake is relatively shallow throughout except for one depression of 11 m near a point formed by the glaciofluvial deposits along the north shore. Local relief is not as great as the Pink Lake site for Ramsay Lake is situated in a col in a small valley. The catchment area is about 400 ha and includes a small lake. A stream flows from the small lake into the boggy northeastern side of Ramsay Lake; an outflowing stream drains the lake to the west.

Aquatic plants are abundant in the lake and cover much of the bottom in shallow water (Aiken and Gillett, 1974). Boggy vegetation borders the lake along the northeast shore. Jack pines are abundant on the sandy glacial deposits, and black spruce, tamarack, and heath plants border the lake in boggy areas. Generally, the forest is similar to that around Pink Lake.

REGIONAL SETTING

Geology

Gatineau Park is part of the Laurentian Upland which forms the southern edge of the Canadian Shield north of Ottawa River. A complex mixture of metasedimentary and igneous rocks of Precambrian age dominated by crystalline limestone, porphyritic syenite, minor granite, and quartz syenite is typical of the region (Hogarth, 1970; Sabourin, 1965). The Laurentian Upland is characterized by rounded hills rising 100 m or more above narrow valleys, a markedly uneven surface, irregular lakes, and youthful drainage. The southern boundary of the upland and the park is formed by the Eardley Escarpment which rises steeply above the lowlands 6 to 8 km north of Ottawa River. Below the escarpment, the topography is subdued; Precambrian rocks outcrop in places, but the uneven Precambrian surface is generally covered by flat-lying Paleozoic limestones. Champlain Sea sediments mantle much of the surface, filling topographic irregularities.

Evidence of only one glaciation, the Wisconsin, has been observed in the area. The rounded hills and polished outcrops of the uplands attest to glacial activity as do the generally sparse and thin glacial deposits. In the valleys and depressions thicker deposits are found. With retreat of the ice the isostatically depressed Ottawa Valley was invaded by the Champlain Sea. The maximum elevation reached by the sea along the Eardley Escarpment was about 198 m. The sea extended northward up major valleys, such as the Gatineau, and submerged low areas to the north of Gatineau Park. The Pink Lake basin was inundated until continued isostatic rebound elevated the area. Ramsay Lake basin was above marine limit, but it is possible that an ice block in the glacial sediments associated with the lake may have delayed formation of the lake basin and the beginning of organic accumulation.

Radiocarbon dates on shells within the Champlain Sea range from a maximum of 12 800 ± 200 (GSC-1859) to 10 000 ± 320 (GSC-1553) years in its waning stages (Lowdon and Blake, 1973; Richard, 1975). In the Meach Lake and Gatineau Valley areas to the east of Gatineau Park, shell dates range from 12 200 ± 160 (GSC-1646) to 11 600 ± 150 years (GSC-842; Richard, 1975). Uplift calculated by Romanelli (1975) suggests an age of 11 000 years for the isolation of the Pink Lake basin from the sea.

Vegetation

The forests of the Gatineau Park area are part of the Great Lakes – St. Lawrence Forest Region with two sections being represented (Rowe, 1972): A small part of the eastern end of the park, in which Pink Lake is situated, is within the Upper St. Lawrence section, and the larger western part of the park, in which Ramsay Lake is located, is within the Middle Ottawa Section (Fig. 1A). The mixed deciduous-coniferous forests of the park area are situated between the coniferous boreal forests farther north and the predominantly deciduous forests of the lowlands to the southeast.

The Middle Ottawa section, which encompasses the major part of the park, is characterized by sugar maple **(Acer saccharum)**, beech **(Fagus grandifolia)**, yellow birch **(Betula alleghaniensis)**, red maple **(Acer rubrum)**, and eastern hemlock **(Tsuga canadensis)** commonly accompanied by white pine **(Pinus strobus)** and red pine **(Pinus resinosa)**. Jack pine **(Pinus banksiana)** is associated with the other two pines on dry ridges and sand flats. White spruce **(Picea glauca)**, balsam fir **(Abies balsamea)**, trembling aspen **(Populus tremuloides)**, white birch **(Betula papyrifera)**, red oak **(Quercus rubra)**, and basswood **(Tilia americana)** occur in varying numbers throughout the area. Ironwood **(Ostrya virginiana)** is common in the understory of hardwoods. Eastern white cedar **(Thuja occidentalis)**, tamarack **(Larix laricina)**, black spruce **(Picea mariana)**, black ash **(Fraxinus nigra)**, red maple, and white elm **(Ulmus americana)** are common in hardwood and mixed-wood swamps. Such southerly species as butternut **(Juglans cinerea)**, bitternut hickory **(Carya cordiformis)**, bur oak **(Quercus macrocarpa)**, white ash **(Fraxinus americana)**, and black cherry **(Prunus serotina)** are present as scattered occurrences.

The Upper St. Lawrence section of the eastern end of the Park and Ottawa Valley below the escarpment has a more broadleaved character than the upland but with the same species dominating. A few species such as largetooth aspen **(Populus grandidentata)**, white oak **(Quercus alba)**, red ash **(Fraxinus pennsylvanica)**, wire birch **(Betula populifolia)**, rock elm **(Ulmus thomasii)**, and blue beech **(Carpinus caroliniana** var. **virginiana)** occur in the valley. Some small pure stands of black maple **(Acer nigrum)** and silver maple **(Acer saccharinum)** are also present. Conifers are abundant only on shallow, acidic, and coarse textured soils.

The dry upland sites surrounding Pink Lake are covered by semi-mature to mature closed stands of hardwoods with small numbers of coniferous species in the understories of some sites (Lopoukhine, 1974). Sugar maple predominates, but beech is not present to any great extent in the immediate vicinity of the lake although it does occur in the area. Ironwood, red oak, white ash, trembling aspen, and white birch are prominent along with mixtures of elm, black ash, red maple, and balsam poplar. Basswood is associated with sugar maple in some stands. White pine occurs as scattered individuals or as small mature stands. Hemlock and white spruce are found as scattered occurrences in the understories of some hardwood stands. Eastern white cedar occurs on open rocky sites near the lake.

The vegetation in the vicinity of Ramsay Lake differs considerably from that surrounding Pink Lake. The shoreline areas of Ramsay Lake support boggy shrub vegetation dominated by ericaceous species. The forests are less mature, conifers are more prominent, and wet sites are more abundant (Lopoukhine, 1974). Some low, boggy areas support

spruce and tamarack. Elm, black ash, red maple, and balsam poplar and/or yellow birch are associated with spruce and tamarack on other wet sites. On drier sites, stands of aspen, white birch, and red oak combined with spruce, balsam fir, and in places white pine and/or red and sugar maple are prominent. The driest sites are characterized by stands containing sugar and/or red maple associated with aspen, white birch, and/or red oak with admixed white spruce, balsam fir, and white and red pine. Beech, basswood, and ironwood are present in the general area, but are even less abundant than in the Pink Lake area.

Climate

Because of its elevation above Ottawa River valley, the climate of Gatineau Park is similar to that normally occurring slightly farther north (Wilson, 1971). The mean annual temperature of the area is 5°C with a mean daily temperature of -9.5°C for January and 20°C for July. The mean annual length of growing season is 190 days. Mean annual total precipitation is 900 mm of which 25 to 29% falls as snow. Usually there is a yearly surplus of water since mean annual potential evapotranspiration is 575 mm. Prevailing winds during the summer are from the southwest and west whereas during the rest of the year they are from the northwest.

STRATIGRAPHY AND RADIOCARBON DATES

Cores were recovered from the deepest parts of both lakes, below 20 m of water at Pink Lake and 11 m of water at Ramsay Lake, using a Brown sampler of 4.4 cm I.D. (Brown, 1956) to obtain the soft sediment below the sediment/water interface, and a Livingstone corer of 3.6 cm I.D. (Deevey, 1965) for the remainder of the core. Ramsay Lake was cored in the fall from an anchored raft, whereas Pink Lake was cored from the ice in winter.

The core from Pink Lake showed 300 cm of fine, algal gyttja, which was silty near the base, overlying grey clay containing pebbles of crystalline limestone. The corer could not penetrate the pebbly layer in the clay at a depth of 320 cm. No marine microfossils were found in the clay, and it is likely that deposition of this clay postdates the Champlain Sea and took place in fresh water. Marine clay may exist at greater depth but could not be reached.

At Ramsay Lake black, algal gyttja occurs to a depth of 850 cm below the sediment/water interface and overlies black, mottled gyttja and black, sandy gyttja with calcareous grey sand partings and layers to a depth of 942 cm. The corer could not penetrate farther into the sand.

The three radiocarbon dates obtained from the Pink Lake core and the five from the Ramsay Lake core are listed in Table 1 and in the percentage pollen diagrams, permitting correlation with the pollen stratigraphy. A corrected age of 540 ± 90 years (GSC-2106; Table 1) on the beginning of the **Ambrosia** rise found in the Ramsay Lake core at a depth of 20 to 25 cm indicates that an error due to the hard water effect is prevalent. This horizon has an historical date of 1825 A.D. (125 years before 1950) or younger (Bond, 1968); therefore, an error of at least 415 years is involved in this date, and it would probably be the minimum error involved in the other dates from this lake. Because of the low rate of sedimentation in Pink Lake, it was impossible to obtain enough sediment from a narrow interval to obtain a date on the **Ambrosia** rise. Because of the abundant limestone bedrock surrounding the lake, however, it is likely that at least an equivalent error is involved.

The variability in the error in the dates due to the hard water effect can be seen when dates from equivalent levels of both lakes, determined by the pollen stratigraphy, are compared. Radiocarbon dates of 3270 ± 260 (GSC-2014) and 3210 ± 90 (GSC-2125) years should be equivalent and are within the statistical errors involved, indicating that the same degree of error from old carbonates is present for both lakes at that time. By contrast, GSC-2016 (7750 ± 170 years) and GSC-2110 (6420 ± 140 years) both date the beginning of the **Tsuga** rise at their respective sites, but they differ by 1830 years suggesting greater contamination at Pink Lake. This assumes that the **Tsuga** invasion of the areas surrounding both lakes was essentially synchronous, a reasonable assumption considering their proximity to each other. The basal date from Pink Lake is not exactly synchronous with either of the two lower dates from Ramsay Lake, so a comparison cannot be made.

PALYNOLOGY

Methods

Absolute pollen content of the sediments in the form of influx rates (grains cm^{-2} $year^{-1}$) was determined for both sites using the exotic pollen method originally described by Benninghoff (1962) and reviewed by Maher (1972).

Table 1. Radiocarbon dates from Pink and Ramsay lakes

	Core Interval (cm)	Laboratory dating No.	Uncorrected age (^{14}C years before 1950)	$\delta^{13}C$ ‰	Corrected age (^{14}C years before 1950)
Pink Lake	132 - 136	GSC-2014	3 410 ± 260	-33.6	3 270 ± 260
	222 - 227	GSC-2016	7 920 ± 170	-36.1	7 750 ± 170
	295 - 300	GSC-1956	10 600 ± 150	-29.3	10 600 ± 150
Ramsay Lake	20 - 25	GSC-2106	650 ± 90	-31.9	540 ± 90
	311 - 316	GSC-2125	3 320 ± 90	-31.9	3 210 ± 90
	542.5 - 547.5	GSC-2110	6 510 ± 140	-31.1	6 420 ± 140
	859.5 - 864.5	GSC-2122	10 300 ± 410	-33.6	10 200 ± 410
	930 - 942	GSC-1963	10 900 ± 180	-27.6	10 800 ± 180

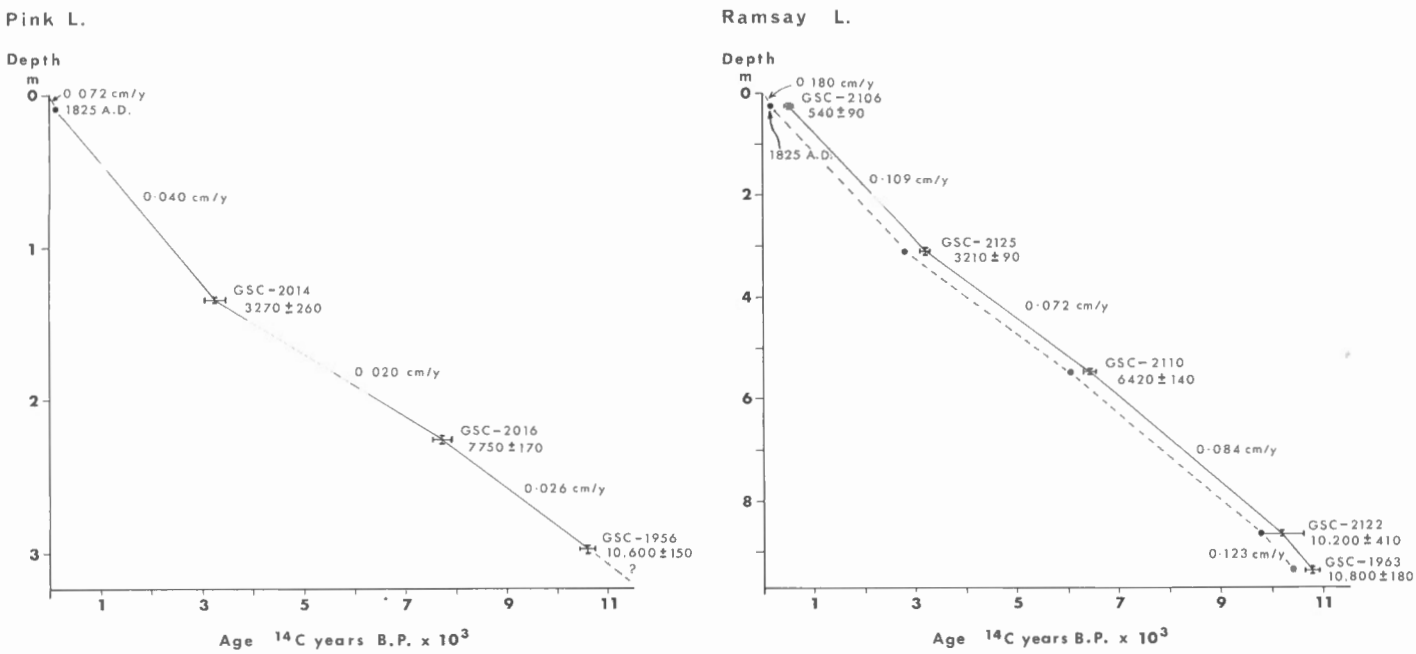

Figure 2. Age/depth diagrams for Pink Lake and Ramsay Lake showing radiocarbon dates and age/depth ratios. Dashed line on Ramsay Lake diagram is the age/depth profile with 415 years subtracted from each date (see text for discussion).

A measured volume of sediment was extracted from the cores using a graduated glass tube, or in the case of very soft sediment, using a liquid displacement procedure in a graduated cylinder. Generally 1 ml, but up to 5 ml, of the loose upper sediment was used. To this sediment a measured volume of **Eucalyptus globulus** pollen suspension of known concentration was added using a glass syringe; the concentration of the exotic pollen mixture had been determined previously using a hemacytometer. Following a modified acetolysis method treatment involving 10% potassium hydroxide, hydrofluoric acid, 50% hydrochloric acid, dilute (10%) nitric acid, and acetolysis mixture, the residues were dehydrated with tertiary butyl alcohol and suspended in silicon oil for counting. A minimum of 100 **Eucalyptus** pollen grains and 300 fossil pollen grains were counted for each sample.

The ratio of exotic pollen counted in each sample to exotic pollen added to each sample could then be used to determine the fossil pollen concentration per unit volume of sediment. Influx rates in cm^{-2} $year^{-1}$ were then calculated by multiplying by the age/depth ratio obtained from a plot of the radiocarbon dates versus depth (Fig. 2; Davis and Deevey, 1964). Percentage values were calculated using a pollen sum comprising total pollen and spores counted excluding local aquatic taxa and any exotic taxa (i.e. **Sarcobatus**).

Results

Percentage Pollen Diagrams

Detailed results are shown in the percentage pollen diagrams (Fig. 3 and 4) where all taxa found are included along with stratigraphy and radiocarbon dates for each site. Nine pollen assemblage zones have been delineated by visual inspection for convenience of discussion based on the kind and abundance of pollen grains and spores (Cushing, 1967). The zonation is based mainly on the relative values, but influx rates also were considered to some extent. The zones are informal and apply only to these two sites and do not necessarily have any regional significance, although they may be correlative with other areas. Because the same pollen zones appear at both sites, the pollen stratigraphy and interpretation will be discussed jointly beginning with the oldest zone.

Pollen Influx Diagrams

The age/depth ratios, a more correct term than sedimentation rates, used to calculate pollen influx were obtained from the respective age/depth diagrams. For Pink Lake (Fig. 2), three radiocarbon dates and the historic date of 125 years B.P. (i.e. 1950-1825 A.D.) for the beginning of the **Ambrosia** rise were used with the intervening sediment interval to calculate the ratios. The age/depth ratio below the oldest radiocarbon date cannot be determined because of the unknown amount of time involved in deposition of this sediment. Therefore, the rate for the overlying sediment is used, but it is probably much too slow a rate considering that the sediment is inorganic and was deposited quickly compared to the organic sediment.

Five radiocarbon dates are available for Ramsay Lake (Fig. 2) including a date of 540 ± 90 (GSC-2106) years for the beginning of the **Ambrosia** rise. This event, however, has an historical age of not more than 125 years based on accounts of settlement in the area (Bond, 1968), and it was this age that was used to calculate the age/depth ratio of 0.18 cm $year^{-1}$ for the upper sediment. Determination of an accurate age/depth ratio for the basal sediments below the lowermost radiocarbon date is not possible for the same reason as given above for Pink Lake, and the rate is assumed to be the same as for the overlying sediment increment. Further complications arise because of the lithology between the two lowermost radiocarbon dates. Intercalated sand and organic lake sediment in this interval yield an age/depth ratio of 0.123 cm $year^{-1}$, although it is probably much too high. If only the organic sediment is used, the ratio is halved; and if the sandy character of the organic sediment is considered, the ratio is quartered, which would be more realistic (Mott, 1978). Consequently, the influx rates would also be reduced to a half or a quarter and would be more in line with the basal influx rates at Pink Lake.

Pollen influx values for the most abundant taxa, as well as the total pollen influx, are shown in Figures 5 and 6. Two features are noteworthy when the two pollen influx diagrams are compared: 1) profiles of individual taxa are similar in character in each, as are the two total influx profiles and 2) the magnitude of the influx values are grossly different.

In both profiles, successive maxima in **Populus, Picea, Pinus, Tsuga,** and **Fagus** follow an early herbaceous pollen zone. The herbaceous pollen zone, contained in the basal mineral sediment, has very low influx rates. Values increase somewhat with the rise in tree pollen in the basal organic sediments, and rise abruptly as **Pinus** pollen increases. At Ramsay Lake the total influx values remain much the same from the **Pinus** increase to the surface, whereas at Pink Lake they decline steadily after the **Fagus** maxima is reached. The cause of this difference can be seen in the **Pinus strobus** and **Betula** pollen profiles. Both taxa remain abundant at Ramsay Lake but decline considerably at Pink Lake.

Why the magnitude of the total influx values at any equivalent depth is considerably higher at Ramsay Lake than at Pink Lake can best be explained by considering the morphometry of the lake basins and the type of lake involved, rather than any differences in pollen production by the vegetation surrounding the sites (Pennington, 1973). Although both lakes have about the same surface area, Ramsay Lake has a catchment area about four times greater than that of Pink Lake which may increase pollen input into Ramsay Lake. However, the small stream draining the upstream lake and catchment area enters Ramsay Lake on the boggy east side, and pollen may be trapped there and not reach the accumulation area. Neither lake is subject to flooding which would flush pollen through the lake basins. These two phenomena can have considerable influence on the pollen accumulation in lakes (Pennington, 1973), but in the case of Pink and Ramsay lakes, they do not appear to be significant factors. The vegetation around the two lakes does not differ radically, but the slightly greater abundance of **Pinus** and **Betula** species at Ramsay Lake may cause, and may have caused in the past, somewhat greater pollen input.

Other factors related to the lakes themselves may be of greater importance. Pink Lake is oligotrophic and produces less sediment than eutrophic Ramsay Lake. Therefore, pollen concentration (i.e. the number of grains per unit volume of sediment) is greater for Pink Lake, except for the upper metre of core at Ramsay Lake where the greater input of **Pinus** and **Betula** pollen produces higher concentrations. As well, Pink Lake is a deep, steep-sided, meromictic lake where sediment has been deposited as a relatively thin layer over a large bottom area and reworking by lake currents has not been important. Conversely, Ramsay Lake is shallow (less than 2 m), except for a small deep area in which the bulk of sediment has accumulated. Redeposition of sediment and pollen from shallow to deep areas is a major factor of concentration of pollen (Davis, 1968). Therefore, because pollen influx is the yearly rate of pollen accumulation on the sediment surface, i.e. number of grains per unit area per year (Davis et al., 1973), the pollen concentrated in the much smaller accumulation area of Ramsay Lake means that influx rates are much higher than at Pink Lake, especially in the upper part of the core where they are almost one order of magnitude higher.

Pollen Stratigraphy

Zone 9 – Herb Pollen Zone. A pollen zone dominated by herbaceous pollen is evident at both sites with **Artemisia** being the most prominent herb pollen type at about 10 and 25 per cent, respectively, at Pink and Ramsay lakes. Also prominent are grass (Gramineae), sedge (Cyperaceae), and pollen of the shrubs alder **(Alnus)** and willow **(Salix).** Numerous other shrub and herb taxa are present in smaller amounts. Among the arboreal taxa, spruce **(Picea),** jack/red pine **(Pinus banksiana/resinosa),** and birch **(Betula)** pollen are the most abundant. All birch grains were not measured, but the small size of many grains indicates that they are probably **Betula glandulosa.** Total influx in this zone is low at Pink Lake – a maximum of 168 grains cm^{-2} $year^{-1}$; influx rates at Ramsay Lake are much higher with a maximum of 6608 grains cm^{-2} $year^{-1}$. However, this is calculated using the high age/depth ratio of the overlying zone, and if a lower rate, as suggested above, of one half or one quarter the value is used, a much lower influx rate is obtained.

The radiocarbon date of 10 800 ± 180 (GSC-1963) years within this zone at Ramsay Lake and the date of 10 600 ± 150 (GSC-1956) years above this zone at Pink Lake indicate that the upper boundary dates at about 10 700 years. Should the zone 9/8 boundary be placed above the peak in willow at Pink Lake it would then be dated 10 600 years and would be equivalent in age to the same zone boundary at Ramsay Lake. If the error of about 415 years suggested by the date of 540 ± 90 (GSC-2106) years on the **Ambrosia** rise is applicable throughout the core, then the 10 700 year age becomes about 10 300 years. Unfortunately, the error determined for near surface sediments may not be the same throughout the sedimentary column as has been noted elsewhere (Mott, 1975).

The maximum age of these sites is not known precisely. Certainly Ramsay Lake is somewhat older than Pink Lake because the Ramsay Lake basin was free for sedimentation following deglaciation or after melting out of any ice block that may have been present in the glacial sediments. The Pink Lake basin only became available when the Champlain Sea level had dropped sufficiently to isolate the basin from the sea. The pollen results also indicate a slightly older age for Ramsay Lake.

*Zone 8 – **Populus** Pollen Zone.* Zone 8 is characterized by peaks in poplar/aspen **(Populus)** pollen of greater than 30 per cent at Pink Lake and greater than 40 per cent at Ramsay Lake. Shrub and herb pollen are generally much less abundant, as is arboreal pollen, except for birch which is slightly more abundant. Some of the birch pollen grains in this zone are larger than those in zone 9 and correspond in size to paper birch **(Betula papyrifera).** Influx values are distinctly greater, attaining about 3000 grains cm^{-2} $year^{-1}$ at Pink Lake and 15 000 grains cm^{-2} $year^{-1}$ at Ramsay Lake, although the latter may be far too high because of the high age/depth ratio used in the calculation. Poplar/aspen pollen remained abundant from about 10 700 to 10 200 years ago, indicated by the date of 10 200 ± 410 (GSC-1963) at Ramsay Lake.

*Zone 7 – **Picea** Pollen Zone.* The abundance of poplar/aspen pollen declines considerably with the increase in spruce pollen in zone 7 but remains in significant numbers. Birch pollen also declines at the beginning of the zone and oak **(Quercus)** pollen increases. Elm **(Ulmus),** ash **(Fraxinus),** and blue beech/ironwood **(Carpinus/Ostrya)** type pollen are consistently present in this zone. Pine pollen and herbaceous types in general are less abundant. **Myrica** is a prominent shrub pollen type at Ramsay Lake. Spruce declines steadily from the peak at the base of the zone as other taxa gradually increase.

Total influx values are higher especially at the beginning of zone 7 where they reach about 4500 grains cm^{-2} $year^{-1}$ at Pink Lake and about 15 200 grains cm^{-2} $year^{-1}$ at Ramsay Lake. Total influx reflects the decline in spruce values towards the top of the zone.

Interpolation between radiocarbon dates gives an age of about 9500 years for the top of zone 7 at Ramsay Lake and 9800 years at Pink Lake.

*Zone 6 – **Pinus** Pollen Zone.* An abrupt increase in jack/red pine pollen marks the beginning of zone 6, the **Pinus** pollen zone, which is characterized by a maximum in jack/red pine pollen followed by a maximum in white pine **(Pinus strobus)** pollen. The former attains maxima of about 25 per cent and more than 50 per cent and the latter more than 20 per cent and more than 50 per cent, respectively, at Pink and Ramsay lakes. Birch and oak pollen are also abundant especially at Pink Lake. Total influx rates are generally high throughout zone 6 and towards the top of the zone reach maximum values of 25 416 grains cm^{-2} $year^{-1}$ at Pink Lake and 51 805 grains cm^{-2} $year^{-1}$ at Ramsay Lake. The zone 6/5 boundary is dated at 7750 ± 170 (GSC-2016) years at Pink Lake and 6420 ± 140 (GSC-2110) years at Ramsay Lake. Because the positioning of this boundary at the beginning of the decline of white pine and the rise in hemlock **(Tsuga canadensis)** pollen is somewhat arbitrary, however, there may be some discrepancy. Some delay may have occurred in the migration of hemlock to the Ramsay Lake area, but 1300 years is too much to be accounted for in this manner. Likely the error due to the hard water effect may be considerably more at Pink Lake.

*Zone 5 – **Tsuga canadensis** Pollen Zone.* Hemlock pollen increases to a maximum of 40 per cent in zone 5 at Pink Lake as white pine declines. Birch and oak are also less abundant but are still prominent, and beech **(Fagus grandifolia)** begins to increase notably. The Ramsay Lake hemlock peak is not as prominent, not reaching even 20 per cent. White pine pollen does not decline as much as at Pink Lake, and birch and oak are not as abundant. Beech is consistently present at Ramsay Lake but its abundance is much less. Influx rates are lower than in the previous zone, declining to less than 10 000 grains cm^{-2} $year^{-1}$ at Pink Lake and to 25 000 grains cm^{-2} $year^{-1}$ at Ramsay Lake, mainly reflecting the large decline in pine pollen influx. Hardwood pollen taxa influx rates generally decline in this zone except for beech and birch at Ramsay Lake.

The estimated age of the upper limit of zone 5, obtained from the age/depth diagrams (Fig. 2), is about 5500 years at Pink Lake and 4800 years for the Ramsay Lake profile. The younger age is probably more reliable because the 5500 year age at Pink Lake is derived from the age/depth curve drawn using the anomalous date GSC-2016 (7750 ± 170). If GSC-2016 is anomalously old for the reasons discussed in the preceding zone description, then any point on the line connecting GSC-2016 and GSC-2014 (3270 ± 260) on the age/depth diagram would also be too old.

*Zone 4 – **Betula-Quercus** Pollen Zone.* Hemlock pollen is greatly diminished in zone 4, and hardwood pollen taxa especially birch and oak are much more abundant. A considerable amount of yellow birch **(Betula alleghaniensis)** is probably involved judging by the size of many of the grains present. Beech is also more abundant. White pine pollen remains at about the same level as in the previous zone. Influx rates generally follow the same trends as percentage values, and total pollen influx rates are similar to those of zone 5.

Similar radiocarbon dates were obtained at both sites for the upper boundary of zone 4 – 3270 ± 260 (GSC-2014) and 3210 ± 90 (GSC-2125) years for Pink and Ramsay lakes, respectively.

*Zone 3 – **Fagus grandifolia** Pollen Zone.* Beech pollen percentages reach a maximum in this zone at both sites, exceeding 10 per cent at Ramsay Lake and almost 20 per cent at Pink Lake. Maple **(Acer)** has maximum values in this zone in both profiles and elm **(Ulmus)** and basswood **(Tilia)** as well in the Pink Lake pollen diagram. Birch remains plentiful, but oak is less abundant. Coincident with these higher values is an increase in hemlock pollen which ranges between about 10 and 20 per cent at both sites.

Total influx values are higher in the Ramsay Lake diagram, reaching a maximum of about 39 000 grains cm^{-2} $years^{-1}$. Total influx for Pink Lake is initially much higher than in the zone below but declines steadily upward in the zone from 19 300 to about 5000 grains cm^{-2} $year^{-1}$. This is a reflection of the influx values for all individual taxa which also decrease greatly.

As determined from the age/depth diagrams, the upper limit of zone 3 is about 1300 years at Pink Lake and about 1500 years at Ramsay Lake.

Zone 2 – Mixed Hardwood Pollen Zone. Zone 2 is not characterized by prominent maxima in any particular taxa such as in the other zones already described, but rather, by declines in some taxa, increases in others, and constant values in some. Hemlock and beech decline steadily throughout the zone, whereas white pine and spruce increase slightly, and others such as maple, elm, and ash have relatively low but constant percentage values. Influx rates are very low at Pink Lake and, in fact, are the lowest (about 1000 grains cm^{-2} $year^{-1}$) since zone 9, but increase upwards in the zone. Ramsay Lake values, although much higher than those at Pink Lake, are relatively low (about 20 000 grains cm^{-2} $year^{-1}$) at the base but increase considerably towards the upper limit of the zone. Hemlock and beech influx rates are low or are declining in zone 2; white pine and spruce rates increase upwards as do the percentage values.

The zone 2/1 boundary at Ramsay Lake was dated at 540 ± 90 (GSC-2106) years but dates historically at approximately 125 years B.P.

*Zone 1 – **Ambrosia** Pollen Zone.* A sharp increase in herbaceous pollen, especially Ambrosieae (ragweed **(Ambrosia)** and similar pollen types), grasses (Gramineae), and smaller amounts of various other herbaceous taxa typify zone 1. Both ragweed-type pollen and grass exceed 10 per cent at Pink Lake, but are less prominent at Ramsay Lake. Also notable are lower values, both percentages and influx, for white pine and hemlock. Total influx rates increase to about 7500 grains cm^{-2} $year^{-1}$ at Pink Lake before declining somewhat at the surface; at Ramsay Lake they increase slightly to a maximum of about 45 000 grains cm^{-2} $year^{-1}$ at the surface.

DISCUSSION

The preponderance of shrub and herb pollen at both sites and the low influx values at Pink Lake in zone 9 indicate that open conditions prevailed in the Gatineau Park region following deglaciation until about 10 700 years B.P. The significance of much higher influx values at Ramsay Lake has been discussed above. Compared to the maximum values obtained higher in the sequence, they are relatively low and indicate open conditions in the Ramsay Lake area as well. **Artemisia**, sedges, and grasses were abundant, but willow, alder, and birch, possibly dwarf birch **(Betula glandulosa)**, were also present forming a shrub tundra environment. Spruce trees may have been present, but if so, they were probably few in number. The pine pollen present can be attributed to long distance transport of these grains into the area where very low local pollen production enhances their abundance. It is not likely that pine trees grew in the area at this early date. The broad expanse of the Champlain Sea,

which still occupied much of lower Ottawa and St. Lawrence River valleys, may have acted as a barrier to early plant migration. The inhospitable landscape of outcrops and lack of soil development in the Gatineau Hills were also factors prohibiting migration of plants. The climate, still affected somewhat by the continental ice sheet whose front was not that far to the north (Prest, 1969), was probably cold and wet as it is in the shrub tundra zone of northern Canada at present.

Beginning about 10 700 years ago, poplar and/or aspen began to invade the area in significant numbers and open ground indicators declined considerably. Influx rates show definite peaks in poplar/aspen pollen, but total values do not suggest closed forests. Comparison with modern influx rates from the aspen parkland region of Saskatchewan leads to the conclusion that a similar parkland type of vegetation cover existed between about 10 700 and 10 200 radiocarbon years ago in the Gatineau region (Mott, 1978). The mobility of poplar and aspen seed, as well as the pioneering ability of these trees, may be the reason for their early incursion into the area (Mott, 1978). Neither spruce nor pine was growing in the area at this time. Some of the birch pollen present may be attributable to white birch **(Betula papyrifera)** and, if so, some white birch trees may have been present.

The Champlain Sea may have been effective in impeding the migration of some plant species, especially trees, allowing those plants with greater mobility, such as poplar or aspen, to reach the area ahead of those incapable of jumping such a broad barrier. No evidence has been found, however, to suggest that the area south of the Champlain Sea in Ottawa Valley had any greater tree coverage at the time of the invasion of poplar or aspen into the Gatineau Park region.

Spruce trees rapidly replaced poplar/aspen on the landscape after about 10 200 years ago judging by the abrupt rise in spruce and decline in poplar/aspen pollen in zone 7. The influx values indicate that spruce actually replaced poplar or aspen although some remained in the area. Total influx values also suggest that spruce did not form a closed forest but probably grew in clumps or groves on suitable sites. Spruce trees then gradually began to decline in abundance and, judging by the decline in total influx rates, they were not replaced immediately by other genera. Oak, blue beech/ironwood **(Carpinus/Ostrya)**, and other hardwood genera show increased pollen values, but it is difficult to say whether or not these trees actually grew in the area. Both jack/red pine and birch, probably white birch, increased in abundance at the expense of spruce. Continuing cool climatic conditions up until this time were probably the main factor limiting development of a closed forest (Davis et al., 1975), but other environmental conditions such as incomplete soil development and lack of suitable sites may also have been involved. By this time the Champlain Sea had receded and no longer formed a major barrier to plant migration in this area.

The continued increase in abundance of birch and jack/red pine trees, as well as increases in oak, ash **(Fraxinus)**, and blue beech/ironwood and possibly even the incursion of maple **(Acer)** about 9800 to 9500 years ago led to the formation of a closed canopy forest in the region. Influx values exceeding 25 000 and 51 000 grains cm^{-2} $year^{-1}$ at Pink and Ramsay lakes, respectively, compared with about 4500 and 15 000 grains cm^{-2} $year^{-1}$, respectively, in the zone below, attest to the change from sparse tree coverage to closed forest (Davis et al., 1975). Pine is certainly over-represented in pollen spectra, but pine trees must have been a prominent member of the forest at this time.

An accurate age on the beginning of any major change in climate about this time is important to determine. Ogden (1967) and Terasmae (1972) postulated a climatic change about 10 000 years ago for the Great Lakes region. Webb and Bryson (1972) suggested that a small climatic change occurred about 9500 years ago based on statistical analysis of pollen results from sites in the American midwest. An age of 9500 years or slightly older seems to be common for sharp increases in influx rates at widely separated sites in northeastern North America, namely New Brunswick (Mott, 1975), northern Maine (Davis et al., 1975), and southwestern Ontario (Mott and Farley-Gill, 1978). A synchronous change over such a wide area would argue for a significant climatic change. The radiocarbon dates involved, however, may not be accurate enough, because of errors due to hard water effect, to resolve any differences due to migration rates and succession.

White pine gradually replaced jack/red pine as the dominant coniferous species in the forest. The abundance of birch trees declined at Ramsay Lake but remained constant or increased at Pink Lake. Oak and several other hardwood genera also increased in numbers as white pine became more plentiful.

White pine abundance peaked about 6500 years ago and then began to decline to be replaced by eastern hemlock. Beech and maple both gained prominence in the forest in conjunction with hemlock, but oak, ash, and blue beech and/or ironwood became less abundant indicating maturing of the forest.

About 4800 years ago hemlock suffered a sharp decline in abundance and remained at low levels until about 3200 years ago. An abrupt decline in hemlock is a common phenomenon throughout much of northeastern North America (Wright, 1977), suggesting the possibility of a pathogenic cause for the decline (Davis, 1976). Beech, maple, and birch continued to increase in the Pink Lake area and birch and beech in the Ramsay Lake area during this interval. Oak also showed a resurgence along with birch during the hemlock decline. Yellow birch **(Betula alleghaniensis)** was probably involved to a greater degree at this time than previously.

Shortly after 3200 years ago, beech and maple reached their greatest prominence in conjunction with a resurgence in hemlock but then began to decline. In the Ramsay Lake area, white pine was slightly more abundant than in the Pink Lake area, but the forest in general was mixed hardwood. The steady decline in influx rates for all taxa at Pink Lake at this time cannot be explained by any vegetation changes and must be related to some peculiarity of sediment deposition, possibly due to a change in sediment distribution patterns that is not reflected in the lithology (Davis et al., 1973).

Some changes in the forest did occur after about 1500 years B.P. The white pine component, especially in the Ramsay Lake area, increased somewhat and spruce increased slightly in both areas. Hemlock became less abundant. Generally the more tolerant hardwood genera were less abundant than previously. A slight deterioration of climate, reflected in the continued decline of the more thermophilous genera, was probably the cause. These changes in the forest vegetation over the last three millenia were not drastic until logging and settlement became widespread in the area from about 1825 to 1850 A.D. The decline in white pine, the prime logging species, can be seen in the white pine pollen profile. Clearing of land for agriculture is responsible for declines in other species, as well as the prominent increases in grasses and weeds. Ragweed **(Ambrosia)** is the most prominent weed genus in both areas, but it is understandably more prominent in the Pink Lake area where farming activity was greater.

The vegetational history of the Gatineau Park region can be summarized as follows. Tundra vegetation dominated by grasses, sedges, **Artemisia**, and other herbaceous plants occupied suitable sites on the young landscape following deglaciation. Alder, willow, and birch shrubs soon became

more prominent. Poplar and/or aspen invaded the area about 10 700 years ago but formed a parkland or woodland with trees occupying only suitable habitats, rather than forming closed forests. Spruce replaced much of the poplar or aspen about 10 200 years ago but did not form a closed forest either. The Champlain Sea may have impeded plant migration somewhat up until this time, but by about 10 200 years ago it had receded down Ottawa Valley to Ottawa and was no longer an effective barrier to plant migration to the Gatineau Park area. Jack pine and/or red pine and birch, probably paper birch, displaced much of the spruce after about 9800 to 9500 years ago, and the forest began to close. Various hardwood genera appeared and white pine increased and gradually replaced other pines. White pine reached its peak abundance about 6500 years ago and was then rapidly replaced by hemlock. Hardwoods were generally abundant in the forest. Beech became very abundant after about 3200 years ago, and hemlock declined to a much lower abundance. By this time the forest had taken on the character that existed when settlers moved into the area. Minor changes in forest composition in the last 3200 years reflect small variations in climate or responses to other environmental conditions. The somewhat more coniferous character of the forest in the uplands of the western part of the park can be seen in the Ramsay Lake pollen diagram in contrast to the more deciduous forest of the eastern end as seen in the Pink Lake pollen spectra. Logging and settlement, which began after about 1800 A.D. and became widespread between about 1825 and 1850 A.D., altered the forests greatly.

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