

# Myrtle Lake: a late- and post-glacial pollen diagram from northern Minnesota<sup>1</sup>

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A pollen diagram from a lake in the former bed of the eastern arm of Lake Agassiz in northern Minnesota records a vegetation of spruce forest followed by immigration successively of *Pinus banksiana* and (or) *P. resinosa* at 10 000 B.P., then *Abies* and *Pteridium*, and still later *Alnus*. Between 8000 and 7000 B.P. prairie and (or) *Quercus* savanna prevailed on the uplands, followed by deciduous forests of mainly *Quercus*, *Ostrya virginiana*, *Fraxinus pennsylvanica*, and possibly *Populus* sp.

Slightly later, *Pinus strobus* migrated into the area, resulting in a gradual decline of pollen of deciduous forest types. *Betula* pollen, however, rises, and there is an indication of a return to prairie conditions prior to 3000 B.P.

During the 8000–7000 B.P. dry interval the lowland vegetation consisted of fens of *Typha latifolia*, *Dryopteris thelypteris*, and Cyperaceae. Later paludification and lateral expansion of the peatland gave rise to rather rich swamps of *Picea mariana*, *Larix laricina*, *Alnus rugosa*, and *Thuja occidentalis*. There are some conspicuous peaks of *Myrica* in the pollen diagram.

The time after 3000 B.P. is characterized by much *Pinus strobus* pollen and minima of deciduous trees and herbs. In the lowlands, formation of raised bogs and poor swamps and fens began, indicating a shift in climate towards wetter conditions. The arrival of white man in the area is reflected by the rise of *Ambrosia*. The shifts in overall peatland types are clearly accompanied by changes in the species composition of *Pediastrum* in Myrtle Lake, indicating corresponding changes in the lake waters.

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## Introduction

The waning of the Mankato ice sheet in late-Wisconsin time left in its wake the large proglacial Lake Agassiz, which occupied large areas in northwestern and northern Minnesota and adjacent Canada. In Minnesota this lake came into existence about 12 000 years ago when the Des Moines lobe and its St. Louis sublobe (of the Alborn phase of Wright and Ruhe 1965) retreated from the Red River and Red Lake lowlands. This lake, Lake Agassiz I, is marked along its southern and eastern rim by the Herman beach (Fig. 1). After a low-level stage resulting from the opening of an outlet to the east in Ontario, Lake Agassiz II (Campbell beach) arose about 10 000–10 500 B.P., when the ice readvanced and closed the eastern outlet (Zoltai 1961). At this time the lake did not reach to the Red Lake lowland. About 9200 B.P. the final retreat of the ice began, and the lake withdrew from the Campbell beach, leaving the lake bed open for vegetational colonization.

Because of a strong climatic gradient to the west in northwestern Minnesota (McAndrews

1966), as well as different soil types, the recent vegetation in the Lake Agassiz area varies greatly. The western part of the basin has clay soils covered by prairie and aspen parkland. In the eastern part patterned peatlands are interrupted by sandy beaches covered by upland vegetation (Heinselman 1963). The peatlands consist of fens, raised bogs, string bogs, swamps, and spruce islands arranged in an intricate pattern determined by surficial drainage.

Much of Minnesota is situated in the tension zone between prairie and deciduous forest. Towards the north this deciduous forest belt thins out and is replaced by aspen parkland (Fig. 1). Pollen studies in Minnesota (Wright *et al.* 1963; McAndrews 1966) point toward an eastern extension of the prairie formation in mid-postglacial time, followed by return of the forest. In the Itasca area of northwestern Minnesota the bogs began their development after this prairie period (Janssen 1967a). A C-14 date from the base of Lindford bog, west of the Myrtle Lake peatland, revealed an age of 4360 B.P. (Heinselman 1963), indicating that most of the peat accumulated after the prairie period. Since then, according to Heinselman, most of the vast peatlands of the Red Lake lowlands resulted from paludification rather than lake

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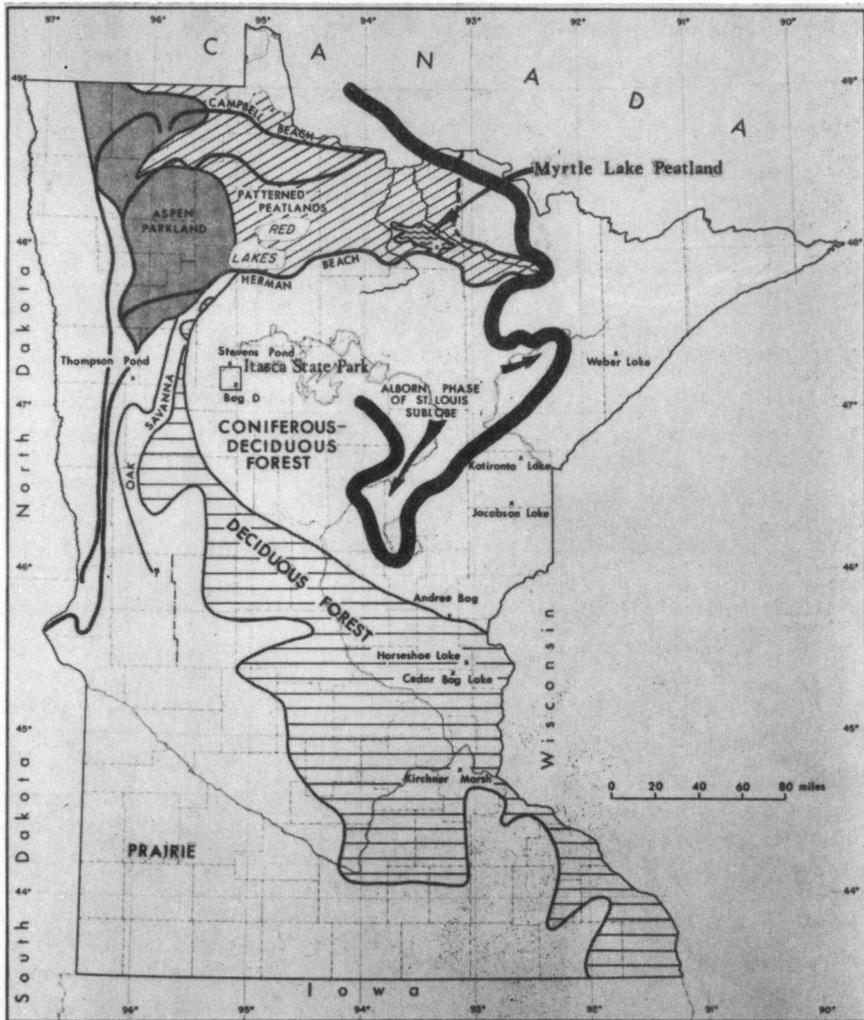


FIG. 1. Map of Minnesota showing the border of the latest recorded ice lobe in the area, beaches of southeastern Lake Agassiz, major recent vegetation types, and pollen sites mentioned in the text. Modified after Leverett (1932), McAndrews (1966), Schoenike (1963), and Wright and Ruhe (1965).

filling, especially along the margin. The question remains, however, what kind of vegetation occupied the area before peat accumulation started on a large scale?

The present work is part of an investigation on the development of these peatlands since the withdrawal of Lake Agassiz. Before detailed work can be undertaken on peat cores, the regional vegetational history of the area must be determined from pollen analysis of a lake sediment. One of the few lakes in the peatland is Myrtle Lake, 40 miles east of Red Lake and close to the eastern margin of the Lake Agassiz

basin. A pollen diagram from this lake is presented in this paper.

#### Myrtle Lake Peatland

The Myrtle Lake peatland is situated on the water divide between the Little Fork and Big Fork Rivers (Fig. 2). Most of the vegetation types of the entire Lake Agassiz peatland are found there. The peat started to accumulate on a gentle slope to the north (Heinselman 1968). According to Heinselman (1963, 1968), the basal sedge peat is typically overlain by forest peat, and then by either *Sphagnum* peat or

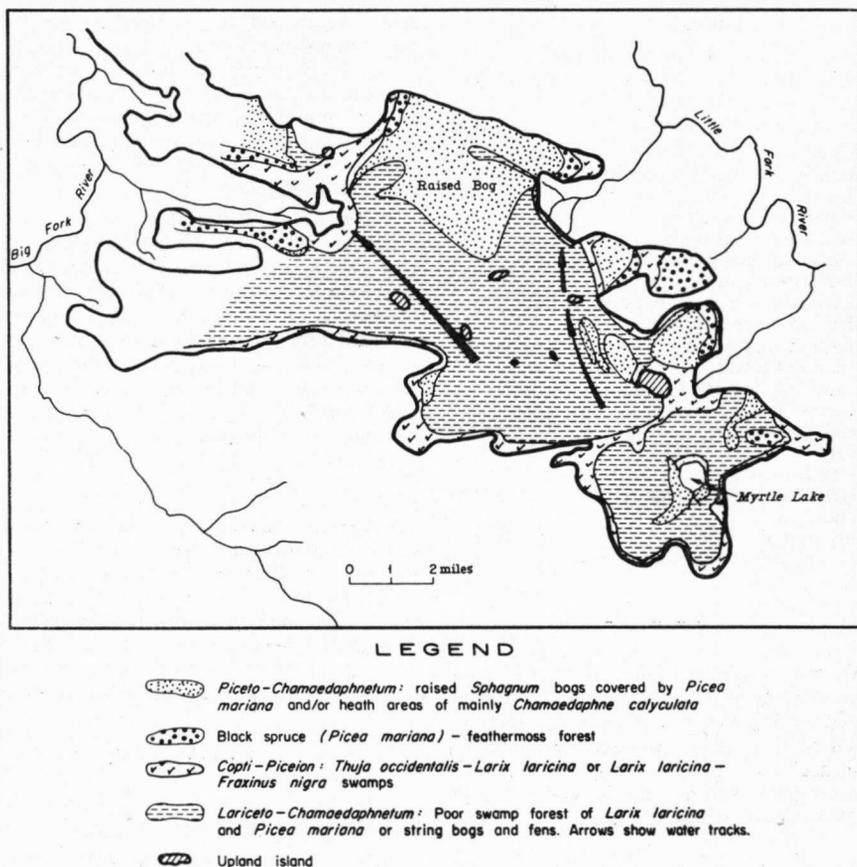


FIG. 2. Simplified vegetation map of the Myrtle Lake peatland. Modified after Heinselman (1968). For explanation see text.

mixed *Sphagnum* and sedge peat, but along the margin the sequence locally starts with forest peat, and in the center the forest layer is locally absent (Fig. 3A).

Myrtle Lake is situated 1.5 miles from the southern end of the peatland (Fig. 3B). It forms a deep pit in the substratum, and therefore its sediments should record the regional vegetation history before the peatland developed. The lake measures about a half mile across and is surrounded on all sides by peatland. At the southern end a remnant of an inflowing stream is found, almost obliterated by peat growth. The stratigraphy of the lake sediment is listed in Table I.

The vegetation types described by Heinselman (1963, 1968) for the area may be grouped (Fig. 2) according to a classification developed for the Itasca State Park area, 100 miles to the southwest (Janssen 1967b). Thus the poor swamp forest described by Heinselman, and probably

the cedar string bog and fens, belong floristically to the *Lariceto-Chamaedaphnetum* (Janssen 1967b). The *Sphagnum* - black spruce - leatherleaf bog forest and *Sphagnum*-leatherleaf-*Kalmia*-spruce heath, both of which are topographically raised (Heinselman 1968), are represented by the *Piceto-Chamaedaphnetum*. The rich swamp forest of Heinselman is the *Copti-Piceion*, or the unit labeled "transition" by Janssen (1967b). Most of the rich swamp forest is found along the margin of the peatland, but one rich *Thuja occidentalis* stand occurs along the northern margin of the lake. It gradually grades to poorer vegetation types toward the north. Along the other sides of the lake only poor swamp forest occurs.

## Methods

### Sampling and Processing

The Myrtle Lake core was taken through the frozen

TABLE I  
Sediment stratigraphy of Myrtle Lake

cm	Strata
0-145	Water
145-440	Dark-brown medium-detritus gyttja
440-505	Fine-detritus gyttja
505-525	Coarse-detritus gyttja
525-570	Medium-detritus gyttja
570-595	Coarse-detritus gyttja
595-695	Medium-detritus gyttja
695-725	Detritus gyttja, slightly finer than above
725-735	Medium-detritus gyttja
735-825	Medium-detritus gyttja with increasing marl content towards the bottom; between 795 and 800 cm, marl content is small
825-852	Marl with some snails
852-863	Dark-brown gyttja, without much marl
863-867	Marl
867-875	Dark-brown gyttja
875-895	Gyttja, with increasing detritus towards the bottom
895-905	Silty gyttja
905-925	Silt with wood and some snails
925-975	Silt with wood
975-1000	Grey-blue clay

surface of the lake by a modified 2-in. Livingstone sampler (Cushing and Wright 1965). Treatment of the core samples included boiling with 10% KOH for 1 minute, sieving the mixture through a fine screen, addition of 10% HCl, and acetolysis at 95 °C for 10 minutes. For microscopic investigation the material was mounted in silicone oil (2000 × csk), without stain.

#### Pollen Diagram

The pollen diagram (Fig. 4) is divided in two parts, one showing the pollen types included in the upland pollen sum, the other those that were left outside the upland pollen sum. Within certain ecological-physiognomic groups the pollen curves have been arranged stratigraphically to show the greatest coincidence of occurrences and to visualize the successional trends.

The pollen numbers are calculated on the basis of two pollen sums (Janssen 1966).

#### 1. The Regional Pollen Sum

The sediment type is lake sediment throughout. Many pollen types show regional values in the pollen diagram because of the large size of the lake and the peatland. This, of course, applies mostly for upland pollen types originating from species that, for most of the postglacial period, cannot have occurred on the shores of the lake. This is recognizable in the trend of the curves at many places in the diagram but especially the spectra above and below spectrum No. 60, where *Picea*, *Betula*, *Pinus*, and *Quercus* show exactly the percentages that are expected on the basis of spectrum No. 60 only.

Excluded from the regional pollen sum are pollen types from taxa that at any time might have grown in the lake itself and thus might show local values: Poaceae (*Zizania*), Cyperaceae (*Scirpus*), open-water types, and ecologically indeterminate types. The algae are also excluded. The black curves and the lined curves (with

scale exaggerated 10×) show percentages based upon this regional pollen sum.

All the types thus excluded from the regional pollen sum are shown on the right side of the diagram. An exception, however, is made for the Poaceae curve, which is almost identical with that of upland herbs and may therefore mostly record upland species of Poaceae, rather than *Zizania*.

#### 2. The Upland Pollen Sum

The upland pollen sum is made up of the pollen types that have an upland origin. Excluded are the types that also were left out of the regional pollen sum, as well as the bog and fen types. An exception is *Betula*, which is included although it might have occurred in the bog as *B. pumila*. Percentages based upon the upland pollen sum are shown as supplemental curves (without exaggerated scale) for *Ulmus*, *Quercus*, *Pinus*, and the total of the upland herbs (including prairie herbs, *Pteridium*, and *Sarcobatus*).

#### Identifications

Identifications of pollen grains were made with the aid of the reference collection of recent pollen grains of the Limnological Research Center. Most of the pollen identifications follow the criteria of Faegri and Iversen (1964), Cushing (1963), and Janssen (1967a). The identification of *Pediastrum* species follows Prescott (1951).

Copies of the pollen counts are available at the Limnological Research Center, University of Minnesota.

## Pollen Analysis

### GENERAL

To provide a useful scheme to discuss parts of the pollen sequence, the pollen diagram has been divided into zones that to a great extent are traceable at Weber, Jacobson, and Kotiranta lakes (Wright *et al.* 1968). The regional vegetation development can thus be compared with that elsewhere in northeastern Minnesota, as well as in other parts of Minnesota.

As the discussion of results will show, similar migration rates of forest dominants may result in similar pollen assemblages that are not necessarily synchronous everywhere. To avoid any time-stratigraphic implication for the zone boundaries, the convention of designating pollen zones by the initials of the site is followed here (Cushing 1967). The list below shows these indices and their literature references.

Weber Lake	WL	Fries 1962
Kotiranta Lake	KL	Wright <i>et al.</i> 1968 (S. Jelgersma)
Jacobson Lake	JL	Wright <i>et al.</i> 1968 (W. A. Watts)
Bog D	BD	McAndrews 1966
Thompson Pond	TP	McAndrews 1966

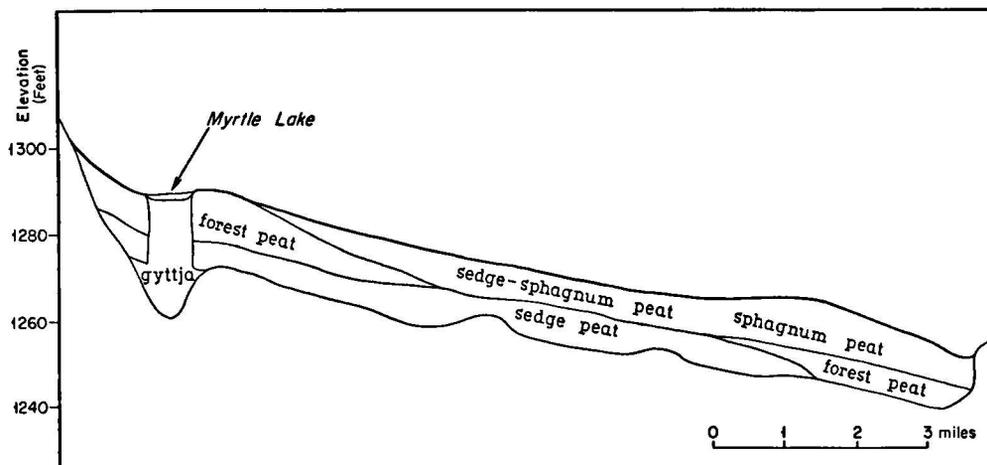


FIG. 3A. Cross section through the Myrtle Lake peatland, showing the main stratigraphic features. After Heinselman, 1963.



FIG. 3B. Aerial view of Myrtle Lake, looking northwest. Patterned fen is light area in background.

Andree Bog	AB	Cushing 1964
Cedar Bog Lake	CBL	Cushing 1963
Horseshoe Lake	HL	Cushing 1967
Kirchner Marsh	KM	Wright <i>et al.</i> 1963 (T. C. Winter)

The locations of these sites in relation to the major recent vegetation formations in Minnesota is shown in Fig. 1.

In the following sections, the regional features will be discussed for each pollen zone, together with interpretation of the development of the Myrtle Lake peatlands. The correlation of regional features with those elsewhere in the state is based on available C-14 dates. Table II shows the synchronicity for a number of sites and may be used throughout the discussion.

#### ZONE ML-1

Zone ML-1 is characterized by high values of *Picea*, low values of *Pinus*, and moderate values of *Quercus*, *Artemisia*, *Larix*, Chenopodiaceae, Poaceae, and Cyperaceae. Although Cyperaceae and *Artemisia* values are slightly higher than in the following zone, they are still too low to indicate a treeless vegetation of the type indicated by the basal sediments at Weber and Kotiranta Lakes (zones WL-1a and KL-1a). Also the values of *Larix* and *Picea* are too high. A C-14 date from the base of the silt layer is  $11\ 120 \pm 210$  B.P. (Y-1782), younger than the zone 1a/1b transition at Kotiranta Lake. It therefore seems reasonable to assume that, at Myrtle Lake, zone 1a is lacking. During that time pollen-free lake clays were deposited. The stratigraphic shift from clay to silt may reflect a withdrawal of Lake Agassiz I from the Herman beach, an event that occurred in northwestern Minnesota before 11 740 B.P. (Y-1327; Shay 1965). Withdrawal of Lake Agassiz resulted in erosion from the area immediately south of Myrtle Lake, possibly by the now largely obliterated stream at the south end of the lake. In the pollen diagram the erosion is indicated by redeposited Cretaceous pollen grains at the base of the zone.

The local vegetation of ML-1 shows a striking parallel with that of JL-1, for Ranunculaceae, *Myriophyllum*, and *Sparganium* are present at both sites. Possibly also *Equisetum* and *Lemna*, abundant at Myrtle Lake, belong to this group of pioneer aquatics, as they have been called by Watts (1967). *Pediastrum simplex* is confined to

zone 1. According to information from P. J. Schroevers, it is a polysaprobic species; its presence is consistent with the sediment type. Also present is *Pediastrum boryanum*, but this species is almost ubiquitous.

Except for *Quercus*, *Ulmus*, and *Ostrya*-type pollen, which are found in late-glacial sediments at all sites in Minnesota, ML-1 has no pollen of other thermophilous trees. *Typha latifolia*, a temperate species now found in Scandinavia only south of the 14 °C July isotherm (Iversen 1954), is absent from the late-glacial at Myrtle, Weber, Jacobson, and Kotiranta lakes. At some sites in and north of the Anoka sand plain are single occurrences of this pollen type, probably a result of long-distance transport. At Andree Bog, Cedar Bog Lake, and Kirchner Marsh it is consistently present, and at Kirchner Marsh the presence of the plant itself is confirmed by macrofossils (Watts and Winter 1966). *Nuphar*, another thermophilous aquatic species (Iversen 1954), is also absent in zone 1b at Myrtle, Weber, and Kotiranta lakes, but it is present to the south. In contrast to *Typha*, long-distance transport cannot account for single occurrences of *Nuphar*, which has a short dispersal distance. The occurrences of pollen of these aquatic types, as well as of thermophilous deciduous trees and of *Abies* and *Pteridium*, all imply a vegetational break at that time in the region near the present southern boundary of coniferous forests. Apparently this area constituted a (climatic?) boundary in the late-glacial as it does today. It is also the area where Wright *et al.* (1968) postulated the northern tree line of *Picea* during the time of zone 1a.

#### ZONE ML-2

At the transition from zone 1 to zone 2 there is a sharp increase of *Ulmus* and *Pinus banksiana/resinosa* type. *Quercus* and *Ostrya* type also increase, and now-exotic deciduous tree types occur regularly. *Picea* decreases gradually to a small percentage, *Pediastrum simplex* disappears, *Equisetum* and *Ranunculus* type decline, and *Nuphar* has a short maximum just above the transition; these trends point to improving climatic conditions as well as quieter lake water, which is indicated also by a change in sediment to pure organic matter. The occurrence of these vascular species and the disappearance of *Pediastrum simplex*, which is the most planktonic

of all the *Pediastrum* species, may also mean falling water levels.

A C-14 date at 890–895 cm places this transition at  $10\ 150 \pm 160$  B.P. (Y-1781), an age that is consistent with most of the hitherto-dated rises in pine throughout the state (Table II). The synchronicity of this feature over such a large area is striking. It is perfectly possible that pine trees did not arrive at the same time everywhere in northern Minnesota. If this is the case, then the pine pollen so easily dispersed over a great distance clearly overshadows the locally produced pollen, resulting in the sharp rise in the pine pollen curve. Preliminary pollen counts of a transition from sandy gyttja to pure gyttja in a core from the raised bog in the northern part of the Myrtle Lake peatland, dated at  $10\ 310 \pm 260$  B.P. (GX-0498; Heinselman 1968), also shows the pine rise at this level.

Zone ML-2 may be divided into zones 2a and 2b. Zone 2a has maxima of several deciduous elements: *Ulmus*, *Quercus*, *Corylus*, and *Ostrya* type. In zone 2b are maxima of *Pinus*, *Pteridium*, and *Abies* and an increase of *Ambrosia*. Throughout zone 2 *Picea* decreases, but most of the decline occurs in zone 2a. The *Larix* percentages remain relatively stable after a fall at the transition from zones 1 to 2.

A similar zone 2 with higher values of mesic forest elements also is present at Weber Lake, but it is absent at most other eastern Minnesota sites. In most of the Itasca sites in northwestern Minnesota the lower pine period is too short, but at Stevens Pond a division on the same basis exists.

The order of the rise and maxima of *Betula*, *Alnus*, and *Abies* follows the migration pattern described by Wright *et al.* (1968). According to them these elements came from the south and appear progressively later towards the north. *Abies* first appears at KM, CBL, and HL before the pine rise; at AB, JL, and WL they come with the pine rise; and at Myrtle Lake they decidedly postdate the pine rise. There is also a shift in the relative position of the *Abies* maximum. In the south it is about at the pine rise or earlier, but at JL, WL, and ML it comes later.

*Alnus* follows the same pattern, but its maximum is delayed with respect to *Abies*. At KM, CBL, HL, and AB the rise of *Alnus* is found before the appearance of *Abies*. The differences in the *Alnus* maximum are even greater. At JL

and WL it is in zone 2b, but at Myrtle Lake it comes in the next zone. The *Betula* maximum is the level where it might be expected: at the end of zone ML-2b, thus intermediate between its position at Jacobson Lake and Weber Lake.

Another species that may belong to this southern migratory group is *Pteridium*. It appears at KM even before *Abies*; towards the north in the Anoka sand plain it appears at the same time as *Abies* and *Pinus*, giving rise to Cushing's *Pinus-Pteridium* assemblage zone. At JL and ML it is later: it appears there with the *Alnus* and *Abies* rise. At Weber Lake, finally, a *Pteridium* zone seems to be absent.

In the Myrtle Lake diagram there is little indication of the character and composition of the lowland vegetation. Pollen grains of *Typha latifolia* are present, but their percentages remain low. Actually the only pollen types that may have come from the lowland are *Sphagnum*, *Picea*, and *Larix*. In boreal regions *Picea mariana* and *Larix laricina* occur on uplands as well as in swamps (Raup 1935; Ritchie 1957; Thieret 1964). According to Heinselman (1963), the oldest peats in the Lake Agassiz area are sedge peats rather than forest peats. In the pollen diagram, however, there is no pollen assemblage that would point to a widespread occurrence of fens. Another possibility is that the area covered by lowland vegetation was smaller than it is now; much of the area might have been covered by upland and floodplain vegetation on the exposed clays of Lake Agassiz, and that it was not paludified until later (Heinselman 1963).

Although in boreal America similar forest types grow on all sorts of soil, *Pinus banksiana* tends to grow on sandy soils (beaches) or is a fire climax on other soil types. On richer soils *Picea glauca*, *Populus balsamifera*, and *Populus tremuloides* are common, the first two especially on floodplains (Raup 1935; Ritchie 1957) such as may have occurred over wide areas of the former lake bed. In all these forest types *Shepherdia* occurs in boreal America, but not *Abies* and *Pteridium*. In a sense the present difference between the boreal *Picea* forest and the temperate pine forest is the same as the difference between zones 2a and 2b in northern Minnesota, and between zones 1 and 2 toward southern Minnesota. The explanation may lie in the comigration of at least the dominant trees of forest communities.

It remains questionable to what extent mesic deciduous elements were present or to what extent their pollen was contributed by long-distance transport. Pollen of *Ulmus* and *Fraxinus* is very abundant at Myrtle Lake. Wood of these trees has been found at the western edge of Lake Agassiz in the Assiniboine valley (Löve 1959). Therefore it seems likely that these trees were part of the regional vegetation at Myrtle Lake. They may have occurred with *Picea*, *Abies*, and *Populus* on the floodplains.

### ZONE ML-3

#### Regional Features

Zone ML-3 is characterized by high pollen values of upland herbs, which suggest more open vegetation, and by high values of deciduous trees and low values of coniferous elements. The zone may be divided in three subzones.

In zone 3a *Quercus*, *Ambrosia*, *Artemisia*, Poaceae, *Typha latifolia*, and *Salix* show values that are maximal for the entire diagram. *Fraxinus pennsylvanica* and *Corylus* increase, and *Picea*, *Larix*, and *Pinus* reach minimal percentages at the top of the subzone. There is a slight increase of *Pinus strobus* type.

At the base of zone 3b *Ostrya* type rises abruptly. *Pinus* reaches a maximum at the top of the zone; it is almost entirely *Pinus strobus* type. *Picea* and *Larix* remain low, *Quercus* decreases, and *Tilia* makes its first appearance.

In zone 3c *Picea* and *Larix* start to increase, but there is a new minimum of *Pinus*, together with a slight rise of the *Pinus banksiana/resinosa* type. Upland herbs reach a new maximum.

A few arguments may be made to include zone 3c in zone 4 instead of in zone 3 because, as at JL, WL, and KL, there is, from the base of zone 3c, a rise of *Abies*, *Picea*, and *Larix*. The counterarguments, which are more persuasive, include the following ones.

1. At JL a slight rise of *Pinus banksiana/resinosa* type clearly is shown at the upper part of zone 3.
2. At JL, WL, and KL *Quercus*, *Ulmus*, and *Ostrya* type have completed their decrease at the base of zone 4. This is not so in zone 3c at Myrtle Lake.
3. There is still a maximum of upland herbs at Myrtle Lake.
4. *Alnus* shows low values in zone 4 at JL, WL,

and KL. At Myrtle Lake *Alnus* shows a maximum.

#### Zone ML-3a

Zone 3a may be considered to represent the period with the greatest impact of the mid-postglacial prairie period. A peak of *Myriophyllum* and *Lemna* may indicate a low water level for Myrtle Lake. Also, the abundant *Typha latifolia* and, at the base of the zone, a sharp peak of the Poaceae (*Zizania* type) are features that likewise may be connected with low water levels. A distinct maximum of upland herbs and deciduous trees implies a climatic cause.

A C-14 date at the base of the zone is  $7850 \pm 120$  B.P. (Y-1780). This is synchronous with Cushing's low-water stage at Cedar Bog Lake ( $7880 \pm 120$ , Y-1197) in his *Dryopteris* subzone. At Jacobson Lake zone 3a is very thin, but at the transition of JL-2 and JL-3 there is a *Quercus* and herb maximum dated at  $7210 \pm 80$  B.P. (Y-1690). This date is later than the Myrtle Lake date, but it is on the maximum of the curves rather than on the rise and therefore should be later. At Weber Lake a horizon of raised herb values was dated at  $7300 \pm 140$  B.P. (U-163), and at Kirchner Marsh a decrease of *Quercus* and increase of upland herbs, along with evidence for a low lake level, were dated at  $7120 \pm 110$  B.P. (Y-1140; Watts and Winter 1966). Also, the *Ambrosia* peak zone in the *Quercus*-Gramineae-*Artemisia* assemblage zone of McAndrews (1966) must be dated somewhere between 7000 and 8000 B.P.

All these changes, traceable over such a large area, must be the result of a major shift to a warmer, drier climate. It may serve as a second synchronous level in Minnesota pollen diagrams, the first being the pine rise at 10 000 B.P. Simultaneously in northern and northeastern Minnesota *Picea* reaches its lowest percentages.

At Myrtle Lake the *Pinus* values at the top of the zone go down to less than 20%, and it would be still lower when calculated on a pollen sum including Poaceae and Cyperaceae. This probably means, according to recent surface samples in areas west of the present coniferous region (McAndrews 1966), that *Pinus* was absent in the Myrtle Lake region, and that the pine pollen grains came from long-distance transport. The slight increase of *Pinus strobus* type may reflect its migration into easternmost Minnesota.

The pollen assemblage resembles that of sub-recent surface samples in *Quercus* savannas west of Lake Itasca (McAndrews 1966). Possibly local prairies were present, although, apart from *Ambrosia*, *Artemisia*, and *Chenopodiaceae*, the number of pollen grains from prairie species remains small. There is, however, a continuous curve for *Iva ciliata* type (cf. also Thompson Pond of McAndrews). The C-14 dates of the *Quercus* rise at bog D, Myrtle Lake, and Jacobson Lake suggest a migration from west to east. At bog D the expansion of the prairie, the rise of *Quercus*, and the suppression of *Picea* started at  $8560 \pm 120$  B.P. (Y-1419). At Myrtle Lake there is a rise of *Quercus* at  $7850 \pm 120$  B.P. (Y-1780). This happens at Weber Lake at  $7300 \pm 140$  B.P. (U-163). At Jacobson Lake the date for the rise is not known but it is before  $7210 \pm 80$  B.P. (Y-1690). Clearly this migration is connected with the eastward penetration by the prairie in mid-postglacial time. At bog D and in the southern parts of Minnesota (KM and CBL) the rise of herbs and *Quercus* began well before 8000 B.P. This also resulted in an early total suppression of *Picea*. In northern and north-eastern Minnesota the savanna arrived much later, and accordingly *Picea* reaches its lowest percentages at a later time in the postglacial. It seems thus that the distribution of *Picea* in this part of the postglacial is similar to that of *Pinus*, just as today. At Weber Lake in the far north-east of Minnesota there is only a slight rise of *Quercus* after a thin zone representing the dry interval of the prairie period. It seems that *Quercus* arrived there too late to profit from a climatic interval unfavorable for its competitors.

#### Zone ML-3b

Zone 3b is characterized by a decrease of upland herbs and an increase of mesic deciduous elements (*Quercus*, *Ostrya* type) and of *Pinus strobus*. In principle the pollen assemblage resembles those that postdate the prairie period at more southern (CBL) and western (BD) sites, where a *Quercus*-*Ostrya* assemblage zone follows a zone of *Quercus* and upland herbs. But because of the less strong impact of the dry interval in the north, this sort of assemblage zone follows immediately, at about 7000 B.P., whereas in the Lake Itasca area and at Cedar Bog Lake the transformation of the

vegetation from savanna to deciduous forest came at about 4000 B.P.

In the lower half of the zone *Pinus* still shows low values, and the pollen assemblage much resembles that of recent samples in the deciduous forest west of Lake Itasca. The upland vegetation apparently was a deciduous type of forest, with *Quercus*, *Ostrya*, *Tilia*, *Fraxinus pennsylvanica*, and *Ulmus*. *Ulmus* pollen reaches a maximum at the base of the zone after minimal values in zone 3a.

But the *Ulmus* curve starts to decrease at the level (spectrum 48) where there is a sudden increase in the ratio of *Pinus strobus* type to *Pinus banksiana/resinosa* type. Although at this level the overall pine percentages seem a little low, it still might mean that at this time *P. strobus* migrated into the area. If so, then it seems likely that *P. strobus* began to replace *Ulmus* and slightly later also *Ostrya* and *Fraxinus pennsylvanica*, for it thrives on the same type of soils. The fate of the deciduous forest thus is clearly determined by the migration of *Pinus strobus*. At Weber Lake pine perhaps never was absent during the postglacial, and accordingly an *Ostrya* zone fails to show up. At Jacobson Lake Wright *et al.* (1968) emphasized a direct suppression of *Quercus* by *Pinus strobus*. At Myrtle Lake this is also true but mostly later in zone 3b. First there seems to be a replacement of *Quercus* by other hardwoods and by pine, a feature that is related to the general migration of pine towards the west at this time.

At the top of the zone *Pinus strobus* reaches such a high percentage (60%) that it must have been present, although it may not have been very abundant.

The early arrival of pine in the northern and eastern parts of Minnesota thus suppresses the deciduous forest quite early. At Myrtle Lake the transition from zone 3b to zone 3c, where *Ostrya* type is low again, is at  $4840 \pm 120$  B.P. (Y-1779). At Jacobson Lake the date is not known, but the fall of *Ostrya* type is in zone JL-3 between  $3920 \pm 120$  B.P. (Y-1691) and  $7210 \pm 80$  B.P. (Y-1690). In the Lake Itasca area the coniferous forest arrives much later (bog D:  $2730 \pm 75$  B.P., Y-1156). It has been argued (Janssen 1967a) that the occurrence of *Picea* in lowlands depends on the type of upland forest. The same relationships exist at most of

the other sites in the coniferous/hardwood formation: when pine arrives *Picea* also returns and thus appears earlier in the northeast than in the south.

#### Zone ML-3c

In zone ML-3c there is a slight decrease of pine. In the curve based upon the regional pollen sum, most of the decline is a result of the increase of *Betula*, which might have been *B. pumila*, the bog birch. But if *Betula* is excluded, as for the upland pollen sum, there still remains a slight decrease of pine.

An increase of upland herbs (*Ambrosia*) is especially noticeable in the curve based upon the upland pollen sum. The pine ratio shifts slightly in favor of *Pinus banksiana/resinosa* type. There is no reaction whatsoever in the other tree types. *Quercus* and *Ulmus* continue their decline, and *Ostrya* type shows a final decrease. It is therefore not very probable that again the deciduous forests encroached upon pine. Perhaps forest fires swept through *Pinus strobus* stands, and semiprairies and *Betula* were involved in the regeneration stages. The increase of *Pinus banksiana/resinosa* type then would be a result of an intensified long-distance transport.

The Jacobson Lake diagram shows essentially the same relationships: a decrease of pine is largely at the expense of *Betula*, and at the same time there is a maximum of upland herbs, with a slight increase of *Pinus banksiana/resinosa* type. There is, however, a synchronicity problem. The base of zone 4 at Myrtle Lake is dated at  $2680 \pm 120$  B.P. (Y-1778); at Jacobson Lake it is 3920 B.P., more than 1000 years earlier. Wright *et al.* (1968) stressed a climatic cause for the changes at the transition from zone 3 to zone 4. And indeed, although in the north *Picea*, *Larix*, and *Abies* return earlier, the expansion of bogs occurred at Myrtle Lake and the Lake Itasca area at the same time, about 2800 B.P. If both phenomena have been triggered by a change to more humid conditions, then the Jacobson Lake date may be in error.

In zone ML-3c *Acer saccharum* reappears after having been absent for some time, a striking parallel with the succession of deciduous forest elements in the Lake Itasca area.

#### Development of the Peatland in Zone ML-3

In contrast to zone 2, the local pollen types

in zone 3 clearly indicate the kind of peatland vegetation. In zone ML-3a there is a peak of *Typha latifolia* followed in zone 3b by a maximum in *Dryopteris* type. Scattered throughout the zone are *Lysimachia thyrsoiflora*, *Campanula uliginosa* type, *Impatiens*, *Rumex orbiculatus* type, *Bidens* type, and *Cicuta* type, indicating a rich fen. Insectiferous pollen grains like these usually do not occur in the regional pollen rain, unless the total pollen deposition is very low or unless these fen types covered unusually large areas. Most of the sedge peats at the base of the Myrtle Lake peatland must have originated during the time of zones 3a and 3b.

In zone 3c there is evidence for formation of swamp vegetation: *Picea* and *Larix* increase, and there are maxima of *Alnus* and *Osmunda* (a mesotrophic species of woods and thickets). Part of the *Betula* pollen grains, which show high numbers in this zone, may have come from *Betula pumila*, today typical of poor swamps, string bogs, and fens. However, in these recent vegetation types *Menyanthes trifoliata*, *Potentilla palustris*, and Ericaceae occur. In the Myrtle Lake diagram, pollen grains of these plants do not occur until in the next zone. Therefore it seems likely that the swamp vegetation must have had a richer character than the present poor *Larix* swamps, fens, and string bogs.

The swamping of the sedge vegetation of the previous zone also is reflected in the diagram by a decrease of the Cyperaceae; and some of the rich fen species drop out.

Much of the forest peat that underlies *Sphagnum* sedge peat at the perimeter of the peatland (e.g. under the raised bog) may have originated during this time. If so, then paludification and expansion of the peatland had started. A C-14 date from amorphous peat underlying forest peat at the base of Lindford bog west of Myrtle Lake is  $4360 \pm 160$  (W-562; Heinselman 1963), which is in agreement with this hypothesis.

But at the northern end of Myrtle Lake, forest peats overlie sedge peats almost up to the surface, so most of the pollen may have come from this area rather than from the periphery of the peatland. Today a conspicuous stand of *Thuja occidentalis* occurs at the northern end of the lake. In zone 3 *Thuja* is not absent, but its percentages remain low and its curve is discontinuous.

*Myrica* shows three peaks in this zone. In continental regions in northern America *Myrica* is not a true bog species, but it occurs in swamps (Heinselman 1968; Gates 1942) and on mineral soils along shores of lakes and rivers. In fact even today there is a belt of *Myrica* along the two stream remnants at the southern end of the lake (Fig. 3A). *Myrica* may have occurred all around the lake. Also during zone 3 time, before the paludification of large areas, greater exposure of beaches may account for the prominence of *Myrica* in the pollen diagram. Another possibility is dust storms, which may have favored *Myrica* in peatland areas.

The pollen zonation is reflected in the behavior of the alga *Pediastrum*. *Pediastrum duplex* f. *cohaerens* is almost restricted to zones 3a and 3b, whereas other *Pediastrum duplex* varieties, *Pediastrum boryanum* var. *longicorne*, and *Pediastrum integrum* are most abundant in zone 3c. *Pediastrum boryanum*, after three striking maxima, decreases strongly halfway through zone 3c. The ecological significance of these phenomena is not known, but they are clearly related to changes in the vegetation of the peatlands.

#### ZONE ML-4

##### Regional Features

At the base of the zone *Pinus strobus* type increases and stays at a relatively high percentage level. The species had migrated much earlier into the area and had remained a minor component in the vegetation, but then, perhaps a result of the climatic change postulated by Wright, it became important. Also, *Abies* reaches maximal values. In contrast, the percentages of the deciduous trees and upland herbs are at their lowest level in the diagram.

The curves of *Pinus* and *Abies* faintly mirror each other in detail, reflecting perhaps fires in *Pinus* stands, after which *Abies* (and *Betula*) come in. According to Heinselman (conversation), a succession from *Pinus* to *Abies* happened not long ago on a rock island in the Myrtle Lake peatland. In the upper part of the zone there are occurrences of *Tsuga*, reflecting the increase of *Tsuga canadensis* east of Minnesota in Wisconsin. Also, one grain of *Fagus* was found in this zone.

At the top of the zone *Ambrosia*, *Chenopodia-*

*ceae*, and *Poaceae* rise as a result of the arrival of the white man. This is the third synchronous level in Minnesota diagram.

There is a decrease of pine in the topmost sample of the core, perhaps the effect of lumbering in the area, which was relatively late in this part of the state.

##### Development of the Myrtle Lake Peatland at the Time of Zone ML-4

In zone 4 *Sphagnum* and Ericaceae appear, indicating that the formation of *Sphagnum* peat began, leading to the present raised bog in the Myrtle Lake peatland and also leading perhaps to the formation of poor swamps and fens. There is a strong rise of *Picea*, *Thuja*, and *Osmunda*. The rise of *Picea* is clearly a result of the increase of suitable habitats. It occurs not only on the raised bog in the northern part of the peatland and on the spruce islands in the area and around the lake, but lateral expansion of the entire peatland (Heinselman 1963) provided potential new areas for colonization at the margin. *Thuja* also profited from the availability of suitable areas along the margin of the peatland, but its rise in this zone might have been a result of an increase of *Thuja* at the northern end of the lake. The same may apply to *Osmunda*. *Larix* shows only a slight rise. At the margin of the peatland new areas became available, but at the same time the rich swamp vegetation from zone 3 became impoverished. At the top of the zone *Larix* decreases, perhaps a result of continued impoverishment and the formation of raised bogs.

There is a continuous decrease of pollen types characteristic for minerotrophic fens. *Alnus*, *Salix*, *Fraxinus nigra*, and *Dryopteris* type decline to low percentage levels. Pollen from minerotrophic herbs occurs mainly in the lower part of the zone. The regional events are accompanied by a striking change in the species of *Pediastrum* in Myrtle Lake. At the transition from zones 3 to 4, *Pediastrum boryanum* ceases to occur, and from then on *Pediastrum* is rare in the lake sediments except for *Pediastrum integrum*, which decreases but still remains present. According to Schroevers (conversation) *Pediastrum* is a genus that generally is absent from raised bogs, but, if present, then *Pediastrum integrum* is the most likely species. On the other

hand, the surprisingly high pH of the lake today (Heinselman 1968) should not prevent *Pedias-trum* from occurring.

### Concluding Remarks

Several sites across Minnesota (bog D, Jacobson Lake, Stevens Pond, Cedar Bog Lake, Weber Lake) show that bog vegetation entered the area during the mid-postglacial time of eastward prairie expansion. *Pinus*, *Picea*, and *Larix* increased at the same time. At the start of the prairie period, *Picea* and *Larix* had disappeared or greatly decreased, as a deciduous type of forest or savanna replaced the conifer/hardwood forests of zone 2, first in the south and west and later in the north. One may visualize relics of the original spruce forest of the late-glacial during the subsequent pine period in favorable sites (bogs), where pine and hardwoods cannot compete with spruce.<sup>2</sup> Finally, these last remnants in lowland areas were destroyed when pine disappeared from the uplands. Spruce returned with the reintroduction of pine in the late post-glacial.

In an earlier paper (Janssen 1967a), the relation between the lowland succession and that of the upland was stressed. In the case of a small basin (Stevens Pond), this relationship is most easily explained by differences in the chemical composition of the runoff water from different types of upland forests. For a vast area like the Myrtle Lake Peatland, such a relationship seems less probable, and here perhaps there is a more direct influence of climate on the peatland vegetation by a change in the proportion of precipitation to evaporation. For most of its development, however, the overall character was that of a soligeneous peatland, and the expansion of the pines in zone 4 on the uplands may have changed the chemical composition of the inflow into the area.

The available radiocarbon dates suggest that raised bogs started to form about 3000 years ago, perhaps initiated by a worldwide change in climate (end of the Hypsithermal: Deevey and Flint 1957). Of course, upland trees are also

<sup>2</sup>In older diagrams from Indiana (Griffin 1950), Michigan (Potzger 1948), and Maine (Potzger and Friesner 1948), where a distinction between *Picea mariana* and *P. glauca* pollen was made on the basis of size, *P. mariana* stays on longer than *P. glauca* during the lower pine period, perhaps in bogs.

influenced by climate, although to a smaller degree. There is therefore a possibility that the arrival of pine in the Lake Itasca area was a result of the same climatic event that caused a pine expansion in the Myrtle Lake area and the start of bog expansion. If the C-14 date for the transition from zone 3 to zone 4 at Jacobson Lake is correct, this would mean that bog expansion started earlier here than in regions more towards the west. Another possibility has been pointed out by Heinselman (1968), who considered that increased erosion and drainage to the east was responsible for an intensified outflow of nutrients. If this is so, then the start of the bog expansion is a local feature and most likely would not be synchronous with the start of bogs in other regions. To solve these problems more analyses from peat cores and C-14 dates across the state are needed.

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NOTE: Table II and Fig. 4 follow.