THE NORTHWARD EXPANSION OF THE ALBERTAN PARKLAND-BOREAL FOREST ECOTONE BOUNDARY IN RESPONSE TO MID-HOLOCENE CLIMATIC WARMING

BY

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ABSTRACT

A 7.09 m lacustrine sediment core was taken from Mariana Lake, Alberta (55°57'N, 112°01'W) to determine if the regional vegetational complex had been affected by the mid-Holocene Hypsithermal. Dating control was provided by 6 radiocarbon dates, with a second degree polynomial fitted to the dates to give an age to depth curve. The basal date of the core is 11 300 ± 110 yr BP. Fossil pollen analysis of the core revealed five distinct pollen zones. Between 11 856 and 10 434 yr BP the study site supported a sparse herb dominated vegetation. A spruce and shrub birch assemblage followed, from 10 434 to 9 100 yr BP, with increased vegetation density. The climate was likely similar to today. This was replaced by a paper birch and spruce complex from 9 100 to 7 638 yr BP likely as a result of warming climate. A mild Hypsithermal effect is recorded between 7 638 and 5 623 yr BP. A forest of decreased crown density was created, with spruce, paper birch and poplar being the major vegetational components. Modern conditions have existed at the site from 5 623 yr BP onwards, though it is hypothesised the regional water budget may have increased slightly around 2 228 yr BP; increased peat development appears to have occurred at this time. Through the use of difference diagrams the site is compared to three other published sites which, along with Mariana Lake, form a north-south transect from the southern Boreal Forest to the northern Alberta Boreal Forest. The hypsithermal is shown to have decreasing effects as one moves northwards along this transect. The form of the hypsithermal vegetation changes varies with distance to the Parkland - Boreal Forest ecotone boundary. It is concluded the parkland did not reach Mariana Lake during the mid-Holocene, though conditions at the site became similar to those at the southern edge of the Boreal Forest that is proximal to the parkland.

A C K N O W L E D G E M E N T S

Many people helped me while I was writing this thesis, making it better than it would have been without them.

Thanks to Julian Szeicz for help throughout the project, especially for teaching me the rudiments of modern ecological work; his demonstration that even PhD. students moan their lack of will power in combating procrastination was very satisfying in the final weeks of this thesis. Chris Larsen also helped significantly with the lab work and "gave" me the chance to have an exciting summer of field work. Katherine McLeod helped get me started in pollen identification and encouraged me when I thought I would never be able to differentiate Black and White Spruce. Ric Hamilton patiently produced the final pollen diagrams. Konrad Gajewski sent the data from the other lakes in the transect.

My friends and roommates (especially Liz and Bob - together in print, even!) helped in all those intangible ways and made sure I didn't get too big an ego from being a pollen counter. Donnie helped get me to fourth year and pulled me through all the rough spots during this year.

Of course, my greatest thanks (and debt) is to my supervisor, Dr. Glen MacDonald. I knew nothing about palynology or palaeoecology but he gave me the knowledge, guidance, and confidence to successfully (I hope) produce a challenging, worthwhile thesis. Thank you, Glen. I am also thankful for the opportunity he gave me to gain valuable (and extremely enjoyable) field experience last summer.

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I dedicate this thesis to my family.

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INTRODUCTION

It is over twenty years ago that Lichti-Federovich published her now classic paper on the postglacial pollen record of Lofty Lake, where she notes that "Alberta is one of the largest areas of Canada about which there is a lack of significant published information on the Late Pleistocene vegetation and ecology" (1970, p 938). Though palynological research has increased since 1970 there remains considerable voids in our knowledge and debate still exists about some of the uncertainties she dwelt with then. One crucial unresolved question raised by her research concerns the northern limit of Parkland extension during the mid-Holocene Hypsithermal, into areas that are now Boreal Forest. Such knowledge has wide applications. It would help determine the thermal magnitude of the Hypsithermal, which is of great importance to various palaeoclimate (eg. COHMAP, 1988) and palaeoecology studies (eg. Zoltai and Vitt, 1990). Understanding the maximum extension of the Parkland is vital to archaeological work in Alberta, as, "interpretation of culture change in prehistory is often linked to environmental change" (Vickers, 1986, p 16). The extent of Parkland expansion is also important for research concerning the origin of disjunct vegetational complexes in Northern Alberta, such as the Peace River Grasslands (White and Mathewes, 1986).

The fossil pollen record from Mariana Lake, Alberta, (55°57'N, 112°01'W), presented in this thesis, will provide a postglacial vegetation history for a poorly researched area of Alberta (Figure 1). This pollen record will reveal if Hypsithermal warming in Alberta created vegetational changes this far north. By constructing difference diagrams between Mariana Lake and a north-south transect of previously researched sites, this thesis will describe Holocene ecotone boundary movements and Boreal vegetational development in Alberta. It will complement existing Parkland - Boreal Forest boundary transects which show Holocene Boreal vegetational development and boundary movement in Manitoba (Ritchie 1964, 1969) and Saskatchewan (Mott, 1973).

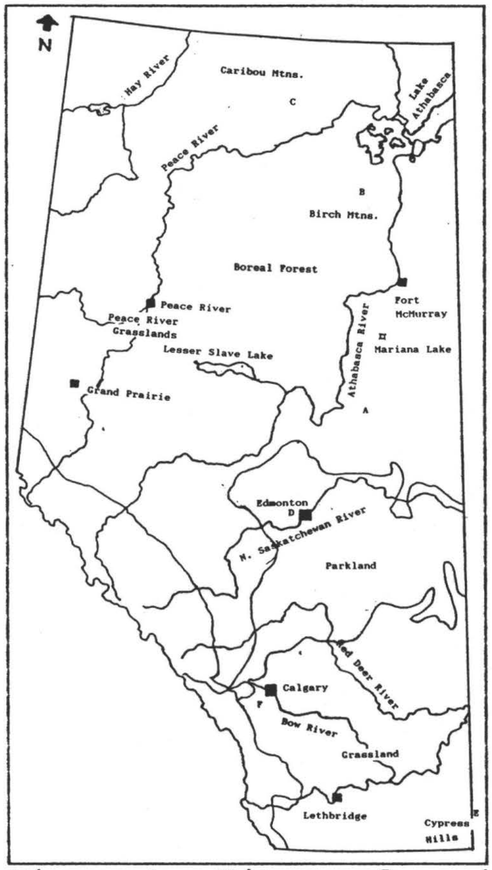


Figure 1 - Sites referred to in text. After Rowe (1972) and Kibuw et al. (1988). See Table 1 for key.

Table 1 - Key to Figure 1

Letter	Site
A	Lofty Lake (Lichti-Federovich, 1970)
B	Eaglenest Lake (Vance, 1986a)
C	Wild Spear Lake (MacDonald, 1987b)
D	Lake Wabamun (Hickman et al., 1984)
E	Harris Lake (Sauchyn, 1990)
F	Toboggan Lake (MacDonald, 1989)

LITERATURE REVIEW

The Pollen Record

The post-glacial pollen record in central and northern Alberta (Figure 1) characteristically contains four or five zones: an initial assemblage, which typically consists of non arboreal pollen (NAP), but sometimes has a significant *Populus* (Poplar) component; a *Picea* (Spruce) dominated zone; a *Betula* (Birch) - *Picea* zone; a mid-Holocene xeric assemblage found at some, but not all, sites; and a *Picea* - *Pinus* (Pine) dominated assemblage virtually identical to the vegetation that currently exists. The mid-Holocene assemblages vary in form and distinctiveness from site to site. The best developed xeric assemblages are from sites near the current Parkland - Boreal Forest border.

The basal zones typically contain relatively high percentages of NAP, such as Gramineae (Grass) and *Artemisia* (Wormwood). This zone extends from sedimentation initiation (~12 000 - 11 000 yr BP) to ~11 000 - 10 000 yr BP. (All references to yr BP refer to radiocarbon years before 1950.) *Populus* is often present, but its importance varies considerably; at Lofty Lake, for example (Lichti-Federovich, 1970), basal *Populus* values reach 50% (the highest levels seen in any Albertan record), while most other sites do not show these high *Populus* levels. Records of this initial pollen zone are found across the province, from northern Boreal Forest sites (Vance, 1986a; MacDonald, 1987b) through to southern sites (MacDonald, 1982, 1989; Mott and Jackson, 1982) with some exceptions in some high altitude sites (Kearney and Luckman, 1987). Interestingly, this herb dominated phase is not as commonly recorded at other sites across the prairies. Mott (1973) did not encounter it in any of his sites in Saskatchewan, nor did Ritchie in his review of eastern plains sites, except at Flin Flon, Sask. (Ritchie, 1976).

The second zone is Picea dominated. It typically occurs from ~11 000 - 10 000 to 9 000 yr BP. Unlike the first zone, this assemblage is universal to all non-montane sites in the Prairie Provinces which extend back to the early Holocene. It is characterised by high Picea frequencies; high NAP percentages are often still present, but at lower frequencies than in the first zone. Pinus and Alnus (Alder) are normally lacking (or are present in very low amounts) in southwest Albertan sites (MacDonald, 1989; Mott and Jackson, 1982), but Betula percentages normally increase during this zone.

The subsequent zone, typified by Betula domination, usually appears between ~9 000 to 7 000 yr BP, after the Picea dominated assemblage. The Betula zone is widespread in Alberta, occurring in most sites except in the extreme north and the Rocky Mountains (MacDonald, in prep). The decline of Betula pollen percentages, at the end of this zone, is relatively synchronous across the province.

The pollen assemblages occurring during the mid-Holocene are the most varied and controversial. Recorded evidence for xeric conditions during the Hypsithermal usually begins by ~8 000 - 7 000 yr BP and ends before 3 500 yr BP (eg. Lichti-Federovich, 1970) but sometimes ends as early as 5 000 yr BP (MacDonald, 1989). As the mid-Holocene Hypsithermal warming occurs sites near current ecotones show changes in their vegetational composition. Alpine and subalpine areas show vegetation changes at timberline and invasion by species which today occupy lower elevations (Kearney and Luckman, 1987, 1983; Luckman and Kearney, 1986; Beaudoin, 1986; MacDonald 1982). In other sites, the Hypsithermal is marked by significant increases in NAP levels (Lichti-Federovich, 1970), lake chemistry and lake diatom species changes (Hickman _et al._, 1984; MacDonald, 1989; Hickman and Klarer, 1984), and the only Holocene occurrences reported from Boreal lakes of pollen from the saline indicator species _Ruppia_ (Ditch Grass) (Hickman _et al._, 1984). Sites away from any ecotone boundaries show little or no significant mid-Holocene changes (Vance, 1986a; MacDonald, 1987 a, b; White and Mathewes, 1986). This relationship between distance to a major ecotone boundary and mid-Holocene vegetation change is well documented elsewhere in the prairies and is discussed by Ritchie (1987, p 127).

Finally, all sites document the establishment of current vegetational assemblages in the late Holocene, during which there has been little change. The commencement of this zone varies primarily with distance from an ecotone boundary; the areas farthest from ecotone boundaries establish modern conditions earliest (eg. Eaglenest Lake about 7 000 yr BP (Vance, 1986a); the Clear Hills and Caribou Mountains around 5 000 yr BP (MacDonald, 1987a, b)). Stabilization of lake levels, timberlines, and modern vegetation ecotones occur between 4 500 - 3 500 yr BP (Hickman and Klarer, 1984; Lichti-Federovich, 1970; Kearney and Luckman, 1983; Hickman et al., 1984; Vance et al., 1983), but always begins before 3 000 yr BP.

Palaeoclimate Conclusions

Fossil pollen zones are often interpreted as representing the response of plant communities to climatic change. Based on fossil pollen and other evidence a reasonably coherent picture of the Albertan palaeoclimate since deglaciation emerges from the literature, though Schweger and Hickman (1989) recently proposed a contrasting one.

The climatic interpretation of the first pollen zone varies because no modern analogue exists for this NAP assemblage. All authors agree the results are equivocal, but some think the zone most resembles Grassland - Parkland assemblages (MacDonald, 1989; Vance, 1986a) while others consider it more tundra like (Mott and Jackson, 1982). These interpretations are usually based on specific indicator species associations which are, or are not, found within the zone. Since the grasslands and tundra contain many similar taxa at the level of taxonomic resolution provided by pollen analysis (generic or family level in many cases), the identification of tundra from grassland is difficult and creates interpretational differences. Vegetational colonization begins quickly after deglaciation. The first zone represents a sparse herb dominated vegetation community growing on thin exposed soils. Both grassland/parkland and tundra interpretations are indicative of arid conditions. However, this assumes that the NAP assemblages occur because of climatic reasons, whereas it is possible the Picea forest simply cannot migrate into the deglaciated terrain as quickly as non arboreal vegetation. This possibility is strengthened by the quick migration of Picea across central and northern Alberta (11 000 - 9 000 yr BP in northern Alberta (Vance, 1986a; MacDonald, 1987b), 11 000 yr BP in central Alberta (Lichti-Federovich, 1970; White and Mathewes, 1986)) from its southern sites (eg. 9 400 yr BP in southwestern Alberta (MacDonald, 1989) which is attributed to unique, short term southerly winds which suddenly allowed Picea to migrate northwards at unprecedented rates (Ritchie and MacDonald, 1986). Given the quick migration of Picea when wind conditions became favourable it would seem migration rate limitations are more significant than aridity in excluding Picea from the first assemblages; however, it is likely the change in wind patterns changed the climate norms, too.

The Picea zone is associated with cooler, moister conditions, though no modern analogue exists for this assemblage. Most authors conclude P. glauca is the predominant Picea species in this zone (White and Mathewes, 1986; Lichti-Federovich, 1970). MacDonald (1989) shows increasing moisture levels during this zone at Toboggan Lake. The source of the Picea was southern glacial refugia (Ritchie, 1976; Ritchie and MacDonald, 1986).

MacDonald (in prep) tests various hypotheses to explain the rise and decline of Betula and finds changing climatic conditions (increasing dryness) to be the only hypothesis that cannot be rejected. Increasing warmth and aridity are put forth by most other authors as the cause of the Picea to Betula change (White and Mathewes, 1986; Lichti-Federovich, 1970).

Beginning by 8 000 yr BP; indications of a warmer, more arid climate are numerous, as are the expressions of this warming. Changing water chemistry and diatom species show decreasing lake levels occurring (Hickman and Klarer, 1984; Schweger and Hickman, 1989), elevation increases in timber lines are recorded (Kearney and Luckman, 1987, 1983; Luckman and Kearney, 1986), Ruppia - a saline indicator -

appears in the pollen record, pointing to lower lake levels and higher evapotranspiration - (Schweger and Hickman, 1989; Hickman et al., 1984), Luckman (1988) shows Athabasca glacier retreat, and an opening of forest canopies at sites near the Parkland ecotone (Vance et al., 1983; MacDonald, 1989; Lichti-Federovich, 1970; Hickman et al., 1984) indicate the change to parkland conditions. Together, these various changes show, unquestionably, warmer drier conditions prevail during this zone.

The timing of the Hypsithermal peak in warmth and aridity varies by site. Vance (1986a) and White and Mathewes (1986) both place it about 7 500 yr BP. Yet, other indicators of the Hypsithermal are only beginning at this point (the Parkland at Lofty Lake exists from about 7 500 to 3 500 yr BP). Maintenance of Ruppia populations ceases at Lake Wabamun by 4 000 yr BP (Hickman et al., 1984) but remain until 3 000 yr BP at other locations (Schweger and Hickman, 1989). Southern Alberta and Saskatchewan have no records which span the entire Holocene because of the dry conditions which exist there prevent continuous deposition of pollen records. The Cypress Hills, located inside the Grassland ecotone, are elevated above the surrounding Prairie resulting in a cooler climate with Parkland conditions, which has allowed lakes to exist there throughout the Holocene; a core from Harris Lake (Sauchyn, 1990) provides evidence for Hypsithermal warming in the southern prairies between 7 700 and 5 100 yr BP. Schweger and Hickman contend most shallow basins filled between 7 500 - 3 500 yr BP (1989). Ritchie (1976) concluded the Boreal Forest began moving southward in the eastern plains around 6 500 yr BP. These studies indicate that the peak of the Hypsithermal occurs before 6 000 yr BP, and by 6 000 yr BP the climate has deteriorated enough that major vegetational changes are progressing.

While this thesis deals primarily with lacustrine paleoecological records there is one peat based study which deserves mention. Nicholson and Vitt (1990) recently studied a peat complex about 6 km south of Mariana Lake. They found that paludification only began in the area about 6 000 years ago. This supports the findings of Zoltai and Vitt (1990) that areas north of 54°30'N across the prairie provinces experienced peat development before 6 000 yr BP while sites south of this latitude did not experience widespread paludification until after 6 000 yr BP.

Schweger and Hickman (1989) offer a different interpretation of Holocene climate. They suggest the climate peaks in terms of aridity and warmth in the early Holocene and experiences increasing moisture and coolness since. They point to data indicating that many basins begin filling around 8 000 yr BP - the time the Hypsithermal (if it occurred) should have been drying out basins. However, this interpretation leaves many observations unaccounted for. The dropping lake levels and increasing saline concentrations, which they discuss in their paper, occur during the zone in which they argue the climate is becoming cooler and moister; these observations contradict, and remain unresolved in their paper. I reject their description of the Alberta Holocene climate in preference for one which includes a Hypsithermal, such as I have outlined.

Most research makes only qualitative climatic conclusions. A few papers attempt to quantify these effects. MacDonald and Reid (1989) reconstruct climate by relating pollen records to climate norms of various ecotones. They conclude there is a mid-Holocene decrease in annual precipitation of 40 mm, and a increase of approximately 120 growing degree-days >5 °C in the Parkland area of Alberta. Vance (1986b) calibrates modern pollen data with meteorological data to derive pollen and climate transfer functions. He concludes a 1.5 °C increase in temperature and a 50 mm decrease in precipitation occurred during the growing season of the mid-Holocene.

Independent climate modelling supports the palynologic palaeoclimate reconstructions. The climate modelling of Kutzbach (1987) produces very similar estimates. His model (based upon global radiative and convective processes, fluid motion equations, and condensation and evaporation factors) indicates higher than modern land surface temperatures (except adjacent to and above the remaining ice sheet) throughout North America by 9 000 yr BP. Between 11 000 and 9 000 yr BP similar precipitation conditions and slightly cooler summers occur; this corresponds well with the timing of the Picea zones at sites in the Boreal Forest. The peak in warming and aridity occurs in the prairies between 9 000 - 6 000 yr BP with temperatures 1°-2° higher than today. Modern conditions (with respect to temperature and precipitation) are established by 3 000 yr BP. These independently generated climate predictions are remarkably similar to the palynologic conclusions.

THE MARIANA LAKE SITE

Mariana Lake is located about 100km SSW of Fort McMurray, Alberta (Figure 1). This is about 134 km north of Lofty Lake (54°44'N, 112°29'W) and 200 km south of Eaglenest Lake (57°46'N, 112°06'W). This area is in the mixedwood subregion of the Boreal Forest (Rowe, 1972). Mariana Lake is located about 225 km north of the Parkland ecotone. Picea glauca (White Spruce) and P. mariana (Black Spruce) are the characteristic coniferous trees with Abies (Fir), Larix (Larch), and Pinus being other prominent conifers. Abies is near its northwestern range limit at Mariana Lake (Ritchie, 1987; Fowells, 1965). Populus tremuloides (Aspen) is the dominant deciduous tree with a significant presence of *Populus balsamifera* (Balsam Poplar) and *Betula papyrifera* (Paper Birch) (Strong and Leggat, 1981; North, 1976; Ritchie, 1987). A larger scale map further identifies Mariana Lake as being in a wet mixedwood Boreal Forest region (Strong and Leggat, 1981). North (1976) classified the local area as *Sphagnum* (peat moss) - *Picea mariana* treed muskeg, though widespread areas of parklike *Pinus banksiana* (Jack Pine) and *Picea glauca* are nearby. The area has an extensive system of discontinuous peatlands; a detailed description of the peatland vegetation in the local area is provided by Nicholson and Vitt (1990).

The lake is located near the western edge of a broad upland plateau at an elevation of about 690 m; this plateau, the Stoney Mountain Upland, is 180 m above the surrounding area (Nicholson and Vitt, 1990). The lake is approximately 800 X 200 m, in an area of abundant sand and gravel which may have been deposited as outwash from a former local glacial lake or may be part of a moraine (Mott, pers. comm.). The glacial till in the area is noncalcareous and consists of bedrock blocks, gravél, sand, and some clay (Ozoray and Lytviak, 1980, cited in Nicholson and Vitt, 1990). The lake has a maximum depth of 6m (Mott, pers. comm.), no inflowing tributaries, and one outflow stream.

The climate of the study area is continental, with 70% of the precipitation arriving in the summer, much of it brought by the mid-Alberta storm track (Strong and Leggat, 1981). Reliable climate norms are difficult to obtain because the closest AES stations operate from May to September only (Atmospheric Environment Service, 1982). Most sources give the mean annual precipitation for the region based on data from Fort McMurray (Strong and Leggat, 1981; Nicholson and Vitt, 1990). For 1951 to 1980, at Fort McMurray, mean annual precipitation was 471.4 mm (Atmospheric Environment Service, 1982). However, this number is clearly too low for the Mariana Lake region; the total precipitation at the May (35 km south) and Algar (25 km north) Lookouts from May to September were 447.2 mm and 417.9 mm respectively - almost equal to the annual total at Fort McMurray (Atmospheric Environment Service, 1982). Strong and Leggat (1981) estimate the Mariana Lake area may have a mean annual precipitation of over 600 mm. The Parkland to the south experiences less summer rain than the Boreal Forest but does receive it evenly through the summer unlike the grasslands which receive most of their rain in June (Strong and Leggat, 1981).

For 1951 to 1981 mean January and July temperatures at Fort McMurray were -21.8°C and 16.4°C. The mean July temperature at the Lookouts was about 1.5°C lower.

METHODS

Coring

A 7.09 m core was taken in 1973 from Mariana Lake by R. J. Mott of the Geological Survey of Canada (GSC) using a modified Livingston piston corer. The core was wrapped in plastic wrap and foil and transported to the GSC laboratory in Ottawa. Here it was kept in cold storage (~5°C) until it was subsampled by Katherine McLeod and Glen MacDonald. The samples were kept at 4°C at McMaster until they were prepared for analysis.

Dating

Chronological control was achieved with radiocarbon dating. Five 5 cm samples of the core were sent to the University of Waterloo for dating. A basal date was provided by the GSC. The results were corrected for C^{13} fractionation. The sedimentation rate for the lake was calculated by fitting a second degree polynomial to the dates.

Pollen Analysis

The sediment was prepared for analysis following MacDonald (1988). 1 mL samples were taken every 10 cm and in some cases every 5 cm. The bottom two samples were very inorganic and were sieved as described by Cwynar et al. (1979). Pollen identification was checked against the

M^c^Master Biogeography Reference Collection and the works of McAndrews *et al.* (1973) and Kapp (1969); pollen taxonomy followed McAndrews *et al.* (1973), Kapp (1969) and Bassett *et al.* (1978). Plant taxonomy follows Budd (1957). Pollen counts were made under a light microscope at 400x. *Picea glauca* and *P. mariana* pollen were differentiated by size and morphology using the morphological characteristics outlined by Hansen and Engstrom (1985). *Populus* differentiation was first attempted by Brubaker *et al.* (1983) who had the aid of a scanning electron microscope to test their counts. I separated *Populus* based only on the morphology differences visible under a light microscope. *Populus balsamifera* has increased surface sculpturing, giving it a rougher and less round appearance, and is *slightly* larger than *Populus tremuloides*. While I feel this differentiation is completely feasible and have confidence in my results I had no chance to practice the *Populus* differentiation before I counted my core, nor could I test myself against known counts. Thus, the *Populus* differentiations should be treated with caution. Pollen sums of terrestrial taxa always exceeded 300 grains, and normally were around 400. The pollen accumulation rates (PAR) were calculated using the standard method described by Birks and Birks (1980).

Loss on Ignition

Loss on ignition (LOI) was used to determine the organic content of the core, at 20 cm intervals. 1 mL samples were dried overnight at 60°C, massed, and then processed as outlined by Dean (1974).

Difference Diagrams

Difference diagrams were constructed between Mariana Lake and 3 other lakes (Lofty Lake, Eaglenest Lake, and Wild Spear Lake) to show ecotonal differences in vegetational composition and rates of change through the Holocene. The four lakes form a North - South transect from the Southern Boreal Forest to Northern Alberta. Lofty Lake is in the southern mixedwood Boreal Forest near the Parkland boundary and shows a clear response to Hypsithermal warming; Eaglenest Lake is in the middle of the Boreal region and does not show any mid-Holocene vegetational changes. Wild Spear Lake (59°15'N, 114°09'W) is in the Lower Foothills subregion of the Boreal Forest (Rowe, 1972); it was selected because its increased elevation and latitude gives it a more northern climate. The diagrams were constructed by taking the difference in the percentage counts between Mariana Lake and each of the other three lakes at 500 year intervals. The closest value to each 500 year interval was selected.

RESULTS

Core Stratigraphy and Radiocarbon Chronology

The core ends in mottled calcareous clay. This extends from 700 - 709 cm. From 692 - 700 cm the core consists of laminated clayey gyttja. The material sampled for the basal radiocarbon date came from this area. Between 675 - 692 cm the core is a laminated algal gyttja. Above this the core is a firm, dark brown gyttja, briefly becoming marly between 600 - 603 cm and 625-627 cm. A <u>Picea</u> needle macrofossil was found at 445 cm (4 888 yr BP). The top 50 cm of the core is unconsolidated and very watery. The radiocarbon results and core stratigraphy are shown in Figure 2. A second degree polynomial was fitted to the dates: $Y = 4.87917*10^{-6}X^2 - 0.119299X - 21.05713$ (Figure 3). The fit has an r value of 98%. The ages for all depths were calculated by solving the equation for X, Y being the depth.

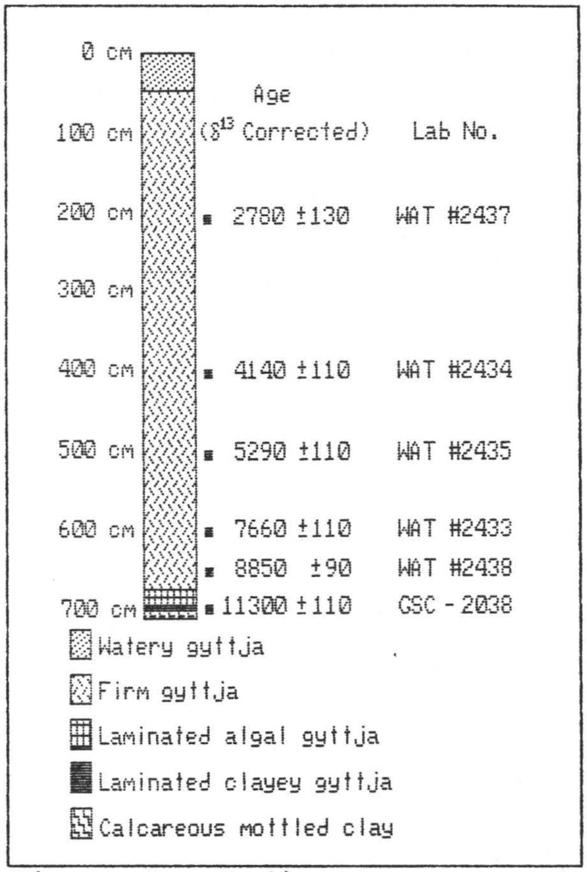


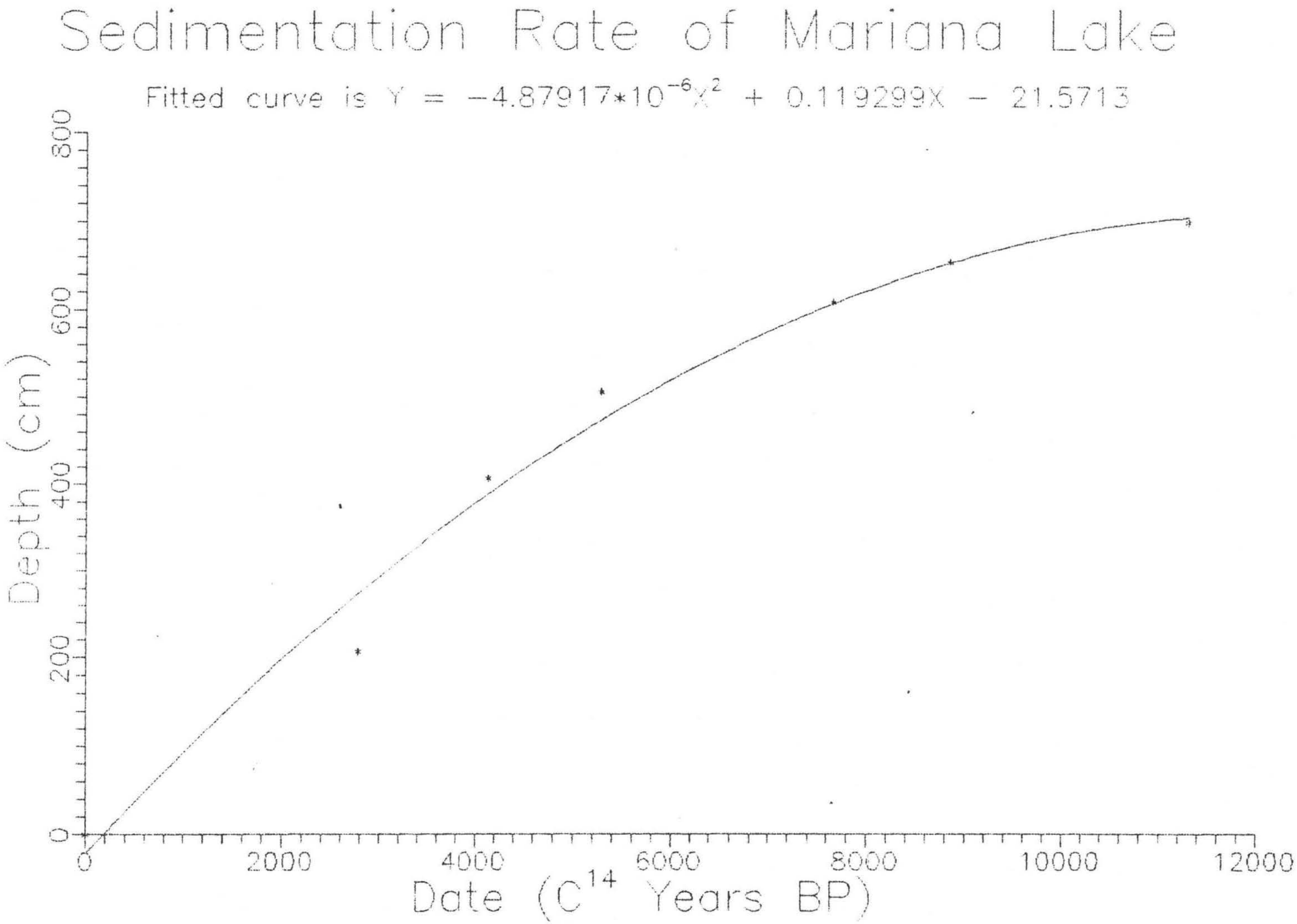
Figure 2 - Sediment stratigraphy and radiocarbon dating.

<u>Loss on Ignition</u>

The organic concentrations (Figure 4) of the core correlate well with its visual stratigraphy. The organic

Figure 3

Curve of the Sedimentation Rate at Mariana Lake



Sedimentation Rate of Mariana Lake
Fitted curve is $Y = -4.87917 \times 10^{-6}X^2 + 0.119299X - 21.5713$
Depth (cm)
0
200
400
600
800
Date (C^{14} Years BP)
0
2000
4000
6000
8000
10000
12000

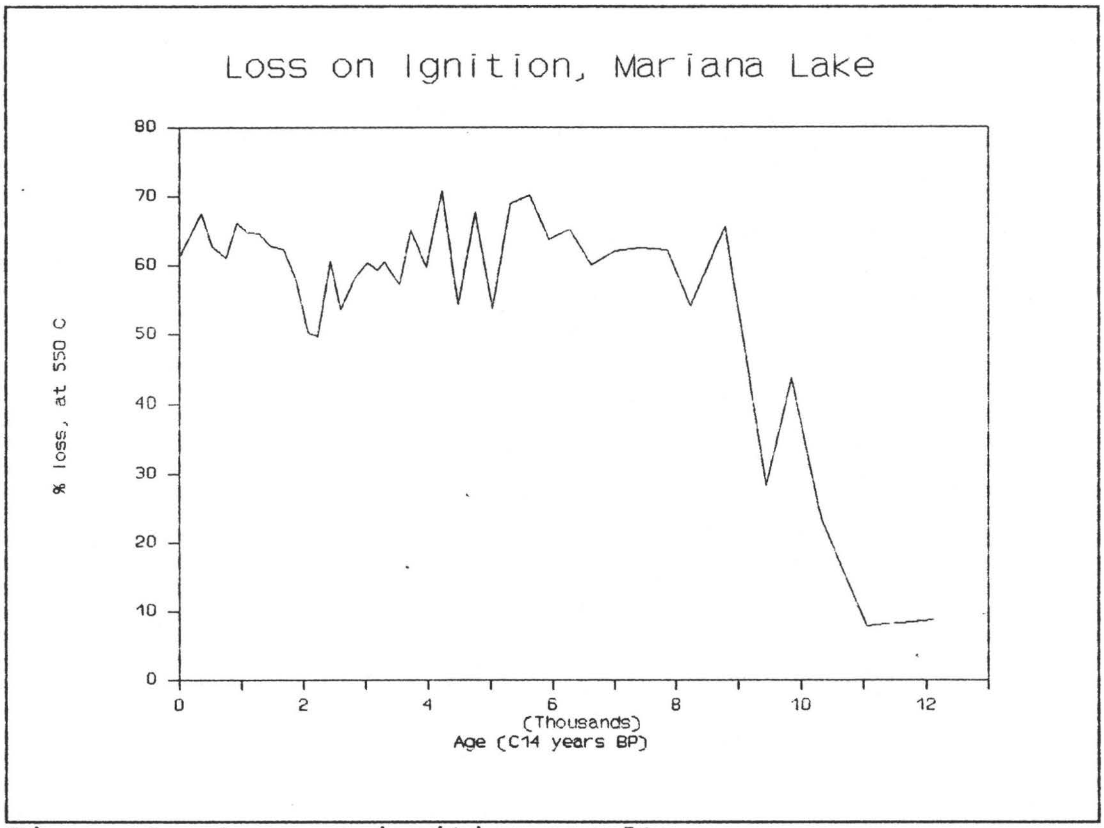


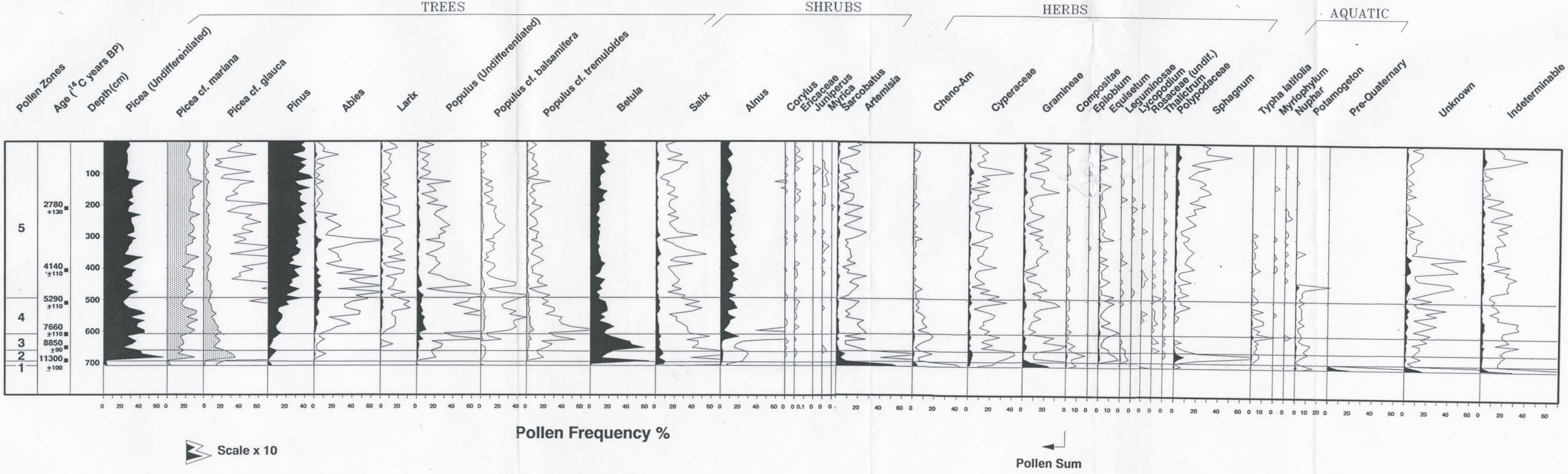
Figure 4 - Loss on ignition results.

level of the sediment is very low from 707 cm to 670 cm (11 856 to 9 447 yr BP) remaining, for the most part, under 40%. This is not surprising; most sites show low organic concentrations during the late Pliestocene and early Holocene. The organic level increases to about 65% in the firm, dark brown gyttja (8 788 yr BP). For the rest of the core the organic concentration remains between 50% and 70%; often, the signal is very noisy. The zone between 7 867 and 5 941 yr BP is the most constant part of the core, with organic concentrations between 60% to 65%.

Figure 5

Pollen Percentage Diagram for Mariana Lake

Pollen Percentage Diagram - Mariana Lake, Alta.



Pollen Stratigraphy

The pollen percentage diagram (Figure 5) was visually divided into 5 pollen assemblage zones. The PAR results are harder to interpret. The total pollen accumulations remains fairly constant until zone 5 where it increases substantially. More troublesome is the noise in the PAR signal; it is so great that is likely obscuring changes occurring in the abundance of the taxa.

Zone 1: Artemisia - Gramineae - Cheno-Am: 707 - 692 cm (11 856 (base) - 10 434 yr BP)

This is the smallest zone in terms of the number of levels counted (3). It is characterised by very high Artemisia (>50%) and Gramineae (>20%) percentages. Cheno-Am (Chenopodiaceae and Amaranthaceae - common names: Goosefoot and Amaranth families) reaches maximum values here (>4%). The only Pre-Quaternary palynomorphs observed in the core are in this zone, below 700 cm. Salix (Willow) is the only large shrub or arboreal species represented in significant amounts. There is little Populus pollen.

Influx values are very low (under 1 000 grains cm^{-2} yr^{-1}). Artemisia and Gramineae have the highest influxes, though Betula rises rapidly at the end of the zone (Figure 6).

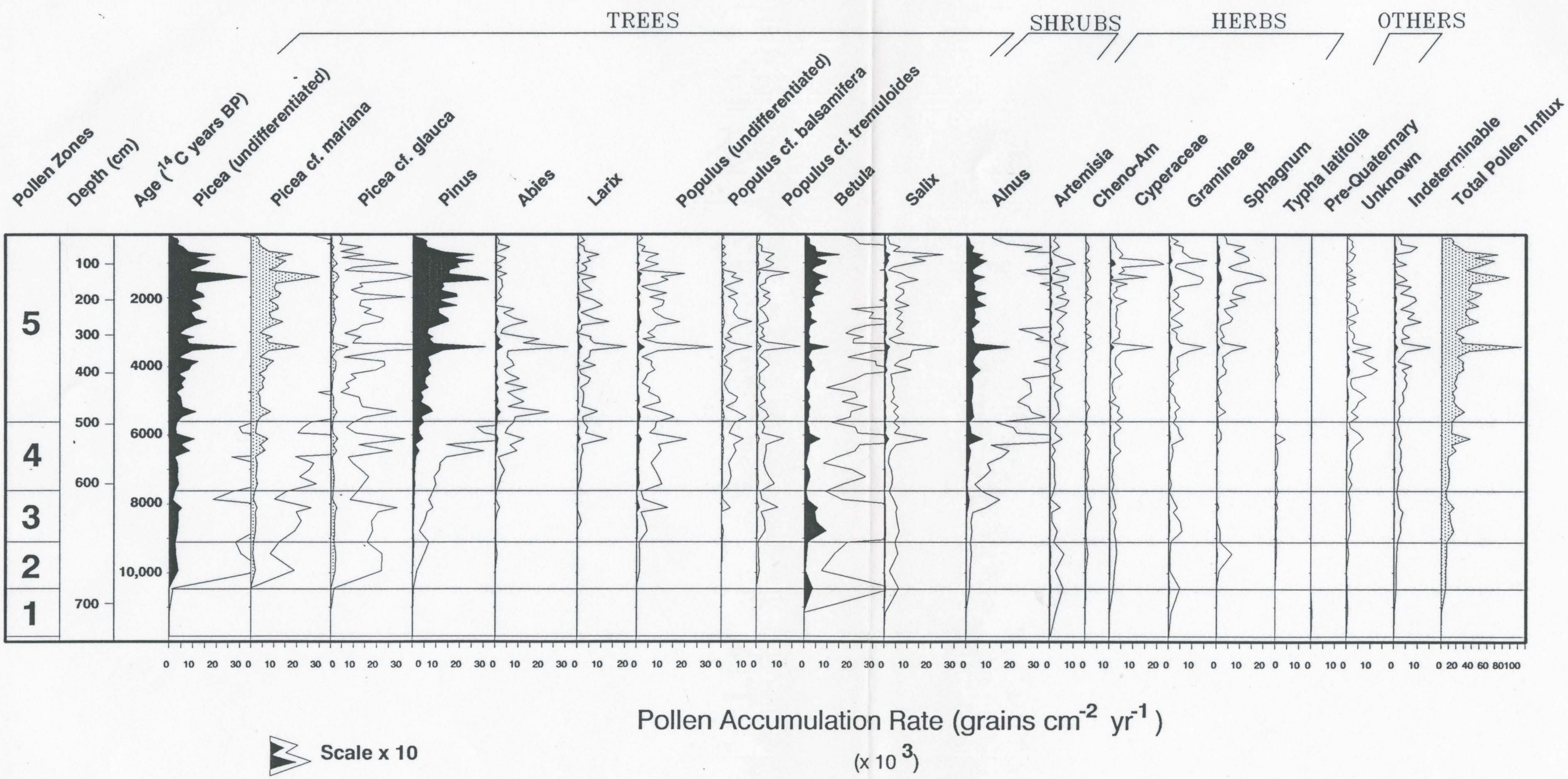
Zone 2: Picea - Betula: 692 - 660 cm (10 434 - 9 100 yr BP)

This zone is marked by the sudden rise of Picea and a brief peak in Betula, concomitant with the sharp decline

Figure 6

Pollen Accumulation Rate for Mariana Lake

Pollen Accumulation Rate - Mariana Lake, Alta.



of *Artemisia* and Cheno-Am. *Picea* reaches its maximum Holocene values of almost 65%. *Artemisia* values remain higher than in any following assemblage (~4% - 7%). Gramineae declines significantly but not as quickly as *Artemisia*. *Abies* and *Populus* appear for the first time, at percentages similar to modern values. Cyperaceae (Sedge Family) and *Equisetum* (Horsetail) arrive and Compositae (Composite family) - virtually all *Tubuliflorae* (Thistle) - reaches its maximum value (almost 2%). *Sphagnum* has a short peak where it too reaches its maximum percentage (>7%). *Typha latifolia* (cat-tail) appears for the first time. While both species of *Picea* invade the area, *P. glauca* is dominant and reaches its maximum percentage value in this section of the core. Most of the *Populus* is *Populus tremuloides*.

The rises in *Picea* and *Betula* are seen in the PAR, with total accumulation rates of over 3 000 grains cm^{-2} yr^{-1}. *Picea glauca* accumulation rates remain constant for the rest of the core.

Zone 3: *Betula* - *Picea*: 660 - 605 cm (9 100 - 7 638 yr BP)

Betula increases quickly at the beginning of the zone (to >55%) then decreases slowly through the zone. *Picea* percentages decrease by 50%, due largely to a decrease in *P. glauca*, though *Picea mariana* also declines. *Populus* values rise through the zone due almost entirely to increases in *P. tremuloides*. *Alnus* values increase sharply at the end of the zone; Larix does likewise. Sphagnum declines to 0% through the zone. Potamogeton (Pondweed) rises.

Zone 4: Picea - Betula - Populus: 605 - 495 cm (7 638 - 5 623 yr BP)

Picea is marginally higher through this zone (20% - 40%), although Picea glauca continues to decrease. Betula declines to 20% by the beginning of the zone and remains between 10% - 20%. Populus increases to its highest values in the core, (>10%). Both P. tremuloides and P. balsamifera increase, but asynchronously; P. tremuloides increases before P. balsamifera and declines towards the end of the zone while P. balsamifera remains high. Pinus slowly increases, but until the end of the zone remains below the 15% value suggested by MacDonald and Cwynar (1985) to be the threshold for local Pinus establishment. Abies, also, slowly rises through the zone. Alnus frequencies increase to 20% at the beginning of the zone and fluctuate between 10% and 20% throughout. Cheno-Am slowly decreases through the zone. Sphagnum is absent after disappearing from the pollen record at the end of the last zone and remains absent for most of this zone. It reappears again around 6 000 yr BP. Typha latifolia values are noisy but appear to decrease slightly by the end of the zone.

Zone 5: Pinus - Picea: 495 - 0 cm (5 623 yr BP - present)

The zone begins with Pinus increasing sharply to

>30%. Pinus then proceeds to increase slowly until approximately 3 000 yr BP when it assumes modern levels (30% - 40%). Picea remains a dominant pollen contributor with little change to its percentage or PAR values, except for a small decrease through the zone in Picea glauca. Abies remains higher than present until about 2 200 yr BP when it decreases markedly. Populus balsamifera continues its decrease from its high in the previous zone until in the top levels of the core it only appears sporadically; Populus tremuloides stabilises quickly at the beginning of the zone at present day levels. Likewise, Betula, Salix and Alnus show no real change. Sphagnum levels increase throughout the zone, showing a marked increase ~2 228 yr BP. Typha latifolia only appears intermittently at the beginning of the zone, then disappears entirely.

Difference Diagrams

Mariana Lake vs Lofty Lake:

Prior to 10 500 yr BP the Mariana Lake postglacial pollen record has significantly higher levels of Artemisia and Gramineae and slightly higher levels of Cheno-Am, Pinus and Picea (Figure 7). Lofty Lake has much greater levels of Populus and higher Betula and Salix levels. The greater Populus levels at Lofty Lake remain until about 8 000 yr BP. Lofty Lake has greater Picea levels at 10 500 yr BP, but otherwise has lower levels throughout the Holocene. Betula

Figure 7

Pollen Percentage Difference Diagram,

Mariana Lake vs Lofty Lake

Mariana Lake - Lofty Lake Difference Diagram

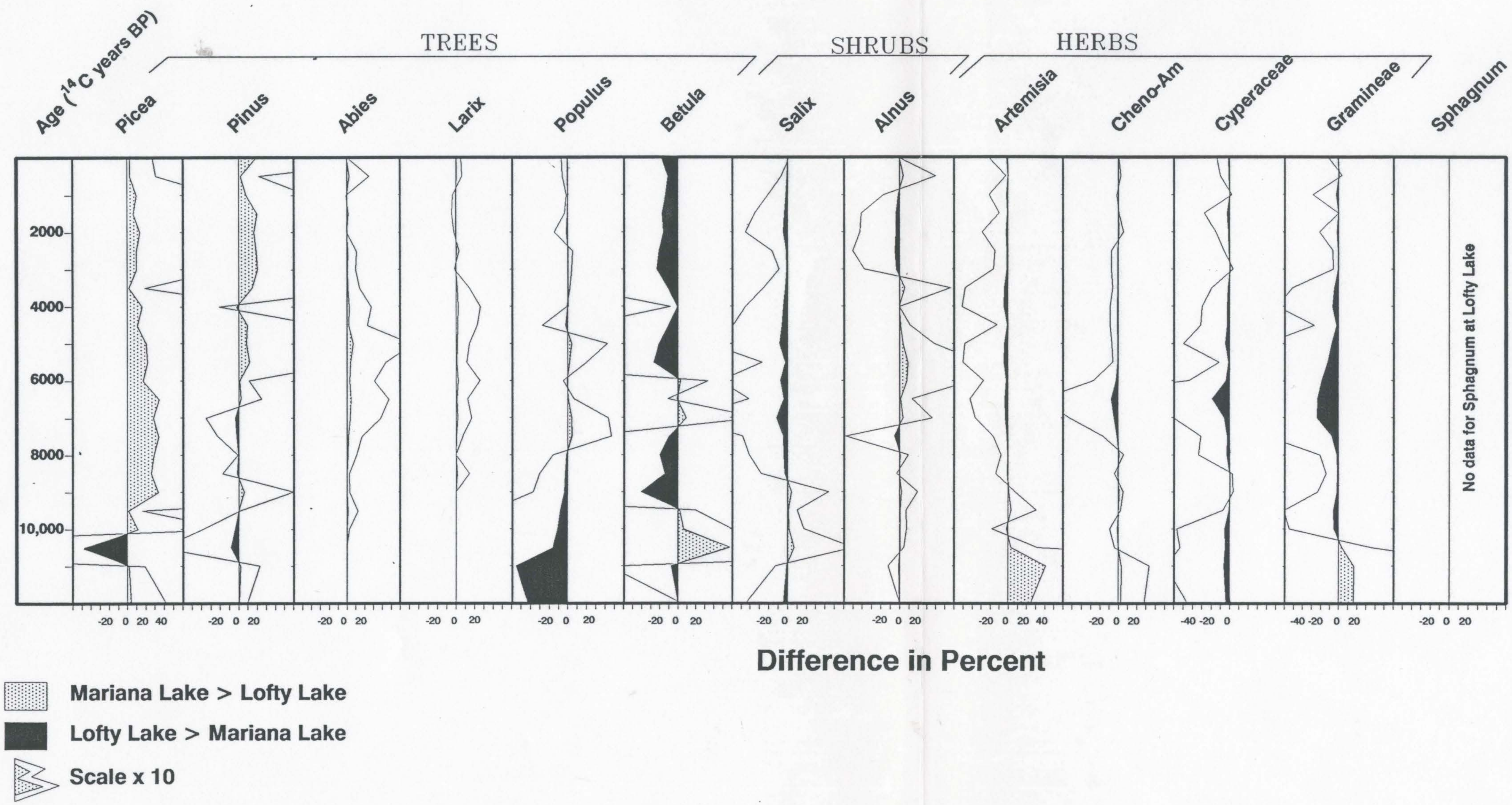


Figure 8

Pollen Percentage Difference Diagram,

Mariana Lake vs Eaglenest Lake

Mariana Lake - Eaglenest Lake Difference Diagram

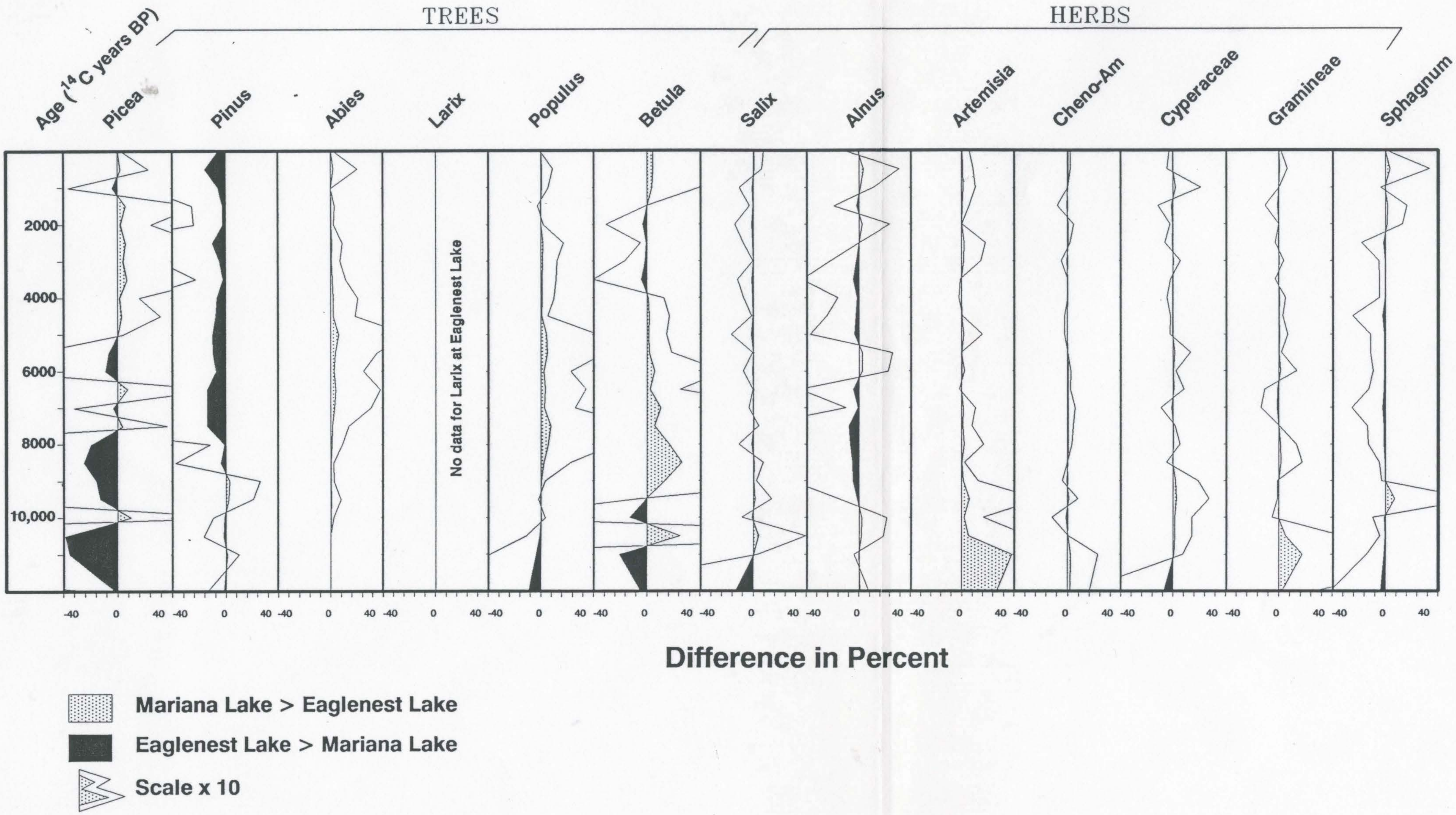
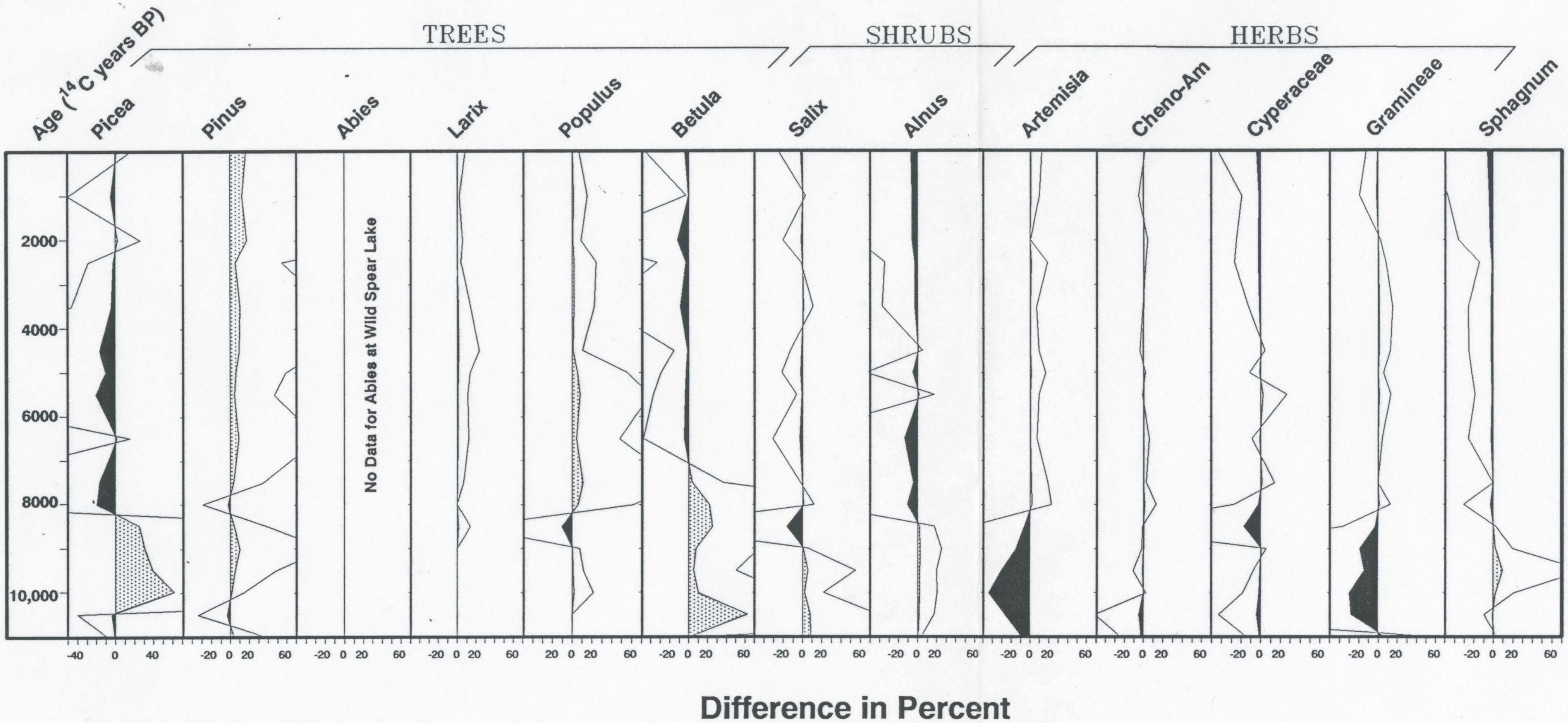


Figure 9

Pollen Percentage Difference Diagram,

Mariana Lake vs Wild Spear Lake

Mariana Lake - Wild Spear Lake Difference Diagram



Mariana Lake > Wild Spear Lake

Wild Spear Lake > Mariana Lake

Scale x 10

is greater at Lofty Lake throughout the Holocene except at around 10 000 yr BP and between 7 500 and 5 000 yr BP. *Populus* is greater at Mariana Lake for about 2 000 years during the mid Holocene. Greater herb values are present at Lofty Lake through this same zone.

Mariana Lake vs Eaglenest Lake:

Picea, *Populus*, *Betula* and *Salix* are significantly greater at Eaglenest Lake in the basal zone (Figure 8). By 10 500 yr BP, these differences end. Likewise, *Artemisia* and Gramineae are greater at Mariana Lake during this initial zone. Between 9 500 yr BP and 7 500 yr BP *Picea* is far more predominant at Eaglenest Lake, but *Betula* is greater at Mariana Lake. Beginning at ~7 500 yr BP and continuing to the present, *Pinus* pollen is more abundant at Eaglenest Lake. *Abies* values are greater at Mariana Lake, but *Abies* is almost nonexistent at Eaglenest Lake, so there is little significance to this. *Populus* is greater at Mariana Lake from about 8 500 to 4 500 yr BP. *Alnus* is greater at Eaglenest Lake between 9 000 and 7 500 yr BP. *Sphagnum* values are greater at Eaglenest Lake in the late Pleistocene and at ~7 000 yr BP.

Mariana Lake vs Wild Spear Lake:

Artemisia and Gramineae values are greater at Wild Spear Lake (Figure 9). These differences exist until approximately 8 500 yr BP. During this zone *Betula*, *Salix* and *Picea* values are greater at Mariana Lake. From about 8

000 to 5 000 yr BP Populus values at Mariana Lake are considerably higher than those at Wild Spear Lake. From ~7 500 yr BP to present, Pinus is consistently higher at Mariana Lake, while during the same time, Sphagnum and Picea are greater at Wild Spear Lake. Larix is more abundant at Mariana Lake from 8 500 yr BP onward, but this is a reflection of the virtual complete lack of Larix at Wild Spear Lake.

Vegetational and Climatic Reconstruction

Zone 1: Artemisia - Gramineae - Cheno-Am: 707 - 692 cm (11 856 (base) - 10 434 yr BP)

The vegetational cover around Mariana Lake during this time is sparse. The high Pre-quaternary values, and very low organic concentrations in the sediment indicate that the eroding runoff (the source of the Pre-Quaternary palynomorphs) is sufficient at this time to wash considerable numbers of the Pre-Quaternary palynomorphs into the lake and that there is little ground vegetation present to prevent the erosion of the mineral soil. This pattern is seen at two of the three lakes Mariana Lake is compared to (Wild Spear Lake and Eaglenest Lake). Previous interpretations of this initial zone vary greatly, from tundra like (Schweger et al., 1981) to parkland/grassland (Vance, 1986a). The differentiation is difficult because: a) the pollen taxa typical of the two vegetational types are similar; b) there does not exist a modern analogue for the pollen assemblage at this widely observed zone; and c) the genera and families contain many species that are widespread in distribution. For example, Ritchie (1987) noted that there are 22 widespread species of Artemisia in Canada, making the palaeoenvironmental information provided by Artemisia pollen minimal. However, this zone clearly represents a sparse, herb dominated landscape with some Salix shrubs. No reliable conclusion can be drawn concerning whether it more resembles tundra or parkland. If the assemblage is predominately herbaceous because of environmental conditions, then the climate was probably drier. However, as discussed earlier, it is possible that arboreal vegetation has not been able to migrate into the area yet in which case we cannot draw any climatic conclusions.

Zone 2: Picea - Betula: 692 - 660 cm (10 434 - 9 100 yr BP)

This zone has no modern analogue. The region is now forested with Picea, with P. glauca being the primary component. The high P. glauca values indicate mesic, but not peaty, soil conditions. This is consistent with modern ecology as peat bogs, which typically produce high P. mariana percentages, would not have had a chance to develop yet; nor are there many indicators that the cool, moist conditions needed for peatland development existed through this zone. The organic content of the sediment has risen significantly from zone 1, but remains rather low - between 20% and 40%. This indicates a more productive lake ecosystem and less mineral inwash than zone 1 but since inorganic deposition is still high vegetative cover must not be thick. Interestingly, the delineation of the zone coincides with briefly maintained high Betula frequencies, occurring just before the rise of Picea. As Picea rises, Betula falls. The Betula may be shrub Betula, decreasing both because the climate is ameliorating and because of the increased competition from arriving Picea. Moist conditions are indicated by the increased frequencies and influx levels of Sphagnum.

Kutzbach (1987) predicts sightly cooler temperatures and similar precipitation for this period, compared to today. The Picea dominated assemblage that has developed indicates climatological conditions similar to modern levels, though we cannot conclude this based on the palynological evidence alone because the assemblage zone has no modern analogue.

Zone 3: Betula - Picea: 660 - 605 cm (9 100 - 7 638 yr BP)

Betula increases rapidly at the beginning of this zone, both as a percentage and in absolute terms. This is accompanied by a decrease in Picea percentage values, though Picea accumulation rates remain constant. This increase in the total amount of vegetation is seen by the small increase in the total pollen influx. The LOI results also record this increased level of productivity around Mariana Lake as the organic composition of the sediment increases to ~60%. If the absolute decrease of Betula that is observed in zone two is caused by competition from Picea, then it is hard to see how the zone 3 increase in Betula could occur without the canopy density decreasing, causing a decline in Picea accumulation rates, which have not occurred. The more likely interpretation, therefore, is that B. papyrifera is now invading the area for the first time. This creates the impression, by examining the pollen percentage diagram, that Picea is decreasing, but the PAR diagram shows Picea has remained constant. The slow decrease in Betula and increasing levels of Populus and decreasing Sphagnum levels indicate the climate is slowly warming and/or becoming drier (Betula seedlings are sensitive to low soil moisture conditions (Fowells, 1965)). This is consistent with the conclusions drawn by MacDonald (in prep) for this period of widespread Betula decline.

Zone 4: Picea - Betula - Populus 605 - 495 cm (7 638 - 5 623 yr BP)

This assemblage zone is interpreted as reflecting the influence of the Hypsithermal. Both species of Populus increase to their Holocene maximums. This is seen on the percentage and PAR diagrams, though the increase is not as marked on the PAR. Betula values slowly decrease through the zone and Picea remains constant. Pollen influx decreases slightly, especially at the beginning of the zone, as expected if the canopy is opening up. Artemisia percentages increase slightly from zone 3. Significantly, Sphagnum does not appear in the pollen record for most of this zone; its disappearance can only be explained by significant decreases in the water budget - ie. decreases in precipitation and/or increases in temperature. The increase of Populus and Artemisia signal the opening of the forest, in response to warmer conditions; both species increase with increased in light levels. Larix, too, a shade intolerant conifer (Ritchie, 1987; Moss, 1955), experiences its maximum levels during this zone, further suggesting the canopy density has decreased. The Hypsithermal effect on the vegetation around Mariana Lake, however, is slight compared to sites closer to ecotone boundaries, such as Lofty Lake. This is expected since Mariana Lake is so much farther into the Boreal Forest. The lack of any appreciable rise in most of the herbs (in fact, Gramineae decreases slightly) indicates the Parkland did not reach Mariana Lake during the mid-Holocene, but it is close enough to the southern boundary of the Boreal Forest to be influenced by the Hypsithermal.

Zone 5: Pinus - Picea: 495 - 0 cm (5 623 yr BP - present)

The beginning of this zone, coincident with the arrival of Pinus to the area, is interpreted as the beginning of modern conditions at Mariana Lake. The record is somewhat hard to read as the total accumulation rates become very noisy. Sphagnum returns, and paralleling Picea mariana, increases slowly throughout the zone, reflecting the peatland development in the area. This is consistent with the peatland study by Nicholson and Vitt (1990). The beginning of modern conditions in the area occurs between 5 500 to 6 000 yr BP in both their study and this thesis. All taxa show little change during the entire zone as do the LOI results, though again the results are noisy. The exception to this stability is the rise in Abies that occurred at the end of zone 4 and is maintained for about one half of zone 5. Abies is often associated with Populus balsamifera stands (Ritchie, 1987) and the pattern of Abies and Populus balsamifera changes are similar on the pollen percentage diagram, but this does not explain what bioclimatic factor is acting to limit Abies during this zone. However, if the annual water budget were increasing, it could be explained. Abies does not grow well on gravelly sands or peat swamps (Fowells, 1965). The area immediately surrounding Mariana Lake is gravelly; At the same time (approximately 2 228 yr BP) as the final decline in Abies, Sphagnum experiences significant increases in its percentage values and in its accumulation rates; the PAR increases are particularly striking. This indicates increased moisture conditions (through increased precipitation and/or lower temperatures) at this time. This increased peatland development, combined with the gravelly soil substrate, is probably limiting Abies. However, such a change must have been subtle as it does not register itself in any other taxa. Such a hypothesis is also difficult to test against other sites since Mariana Lake is in a moist part of the Boreal Forest that contains no other lacustrine based published sites.

Ecotonal Development and Change

All four sites (Lofty Lake, Mariana Lake, Eaglenest Lake and Wild Spear Lake) are in the Boreal Forest; the first three are in the mixedwood subregion while Wild Spear Lake is in the lower foothills (Rowe, 1972). The first three sites lie in an almost straight north-south transect, with a total longitudinal variation of only 0°28'. The latitudinal change is 3°03'. Wild Spear Lake is another 1°29" north of Eaglenest Lake, but its elevation gives it a more northern climate still. Thus, the four lake transect provides an excellent chance to study the development of the modern Albertan Boreal Forest.

The remarkably consistent timing of vegetational changes across the four sites (see Table 2) demonstrates that the Boreal Forest is an area of shared characteristics and responses not just in modern times but throughout the Holocene. Following deglaciation, which varied from site to site (Dyke and Prest, 1987), the independently established pollen zone boundaries are very similar to each other. This indicates that the most plausible causal agent of vegetational change through the Holocene in Alberta is climate. Other explanations such as disease, individual site characteristics, fire, or interspecific competition are unable to explain the synchronous changes occurring in such a wide spatial area without resort to _ad hoc_ explanations.

Table 2 - Pollen Zone Comparisons

Zone	SITE			
	Lofty L.	Mariana L.	Eaglenest L.	Wild Spear L.
1	base to 11 000	base to 10 434	base to 11 000	base to 10 000
2	11 000 to 9 200	10 434 to 9 100	11 000 to 9 532	10 000 to 9 000
3	9 200 to 7 500	9 100 to 7 638	9 532 to 7 500	9 000 to 6 000
4	7 500 to 3 500	7 638 to 5 623	7 500 to present	6 000 to present
5	3 500 to present	5 623 to present		

Lofty Lake is the most southern site. Its basal zone is unique because of its very high _Populus_ values. This zone contains much higher arboreal values (_Populus_ and _Salix_) than Mariana Lake, which has higher herb values. Whether this reflects earlier vegetational development because of its southerly position or unique site characteristics cannot be answered because of dating uncertainties and the uniqueness of the vegetational assemblages of this time period. Eaglenest Lake, like Lofty

Lake, has higher arboreal percentages and lower herb percentages in the basal zone than Mariana Lake. However problems with the dating of the Eaglenest Lake core (see Vance, 1986a) make detailed comparisons uncertain at the basal level. The Wild Spear Lake core is not as old as the others, so comparing the basal zone between it and Mariana Lake creates apparent differences on the difference diagram which reflect differences in the timing of the vegetational development, not the composition itself. Common to all four lakes, however, is the brief period of low productivity with sparse vegetational cover. Artemisia, Gramineae, Cyperaceae, Cheno-Am, Salix, and Populus are the predominant taxa represented. The differences in the start of lake formation (and subsequent pollen deposition) are created by differences in glacier retreat (Dyke and Prest, 1987).

Above the basal zone, the difference diagrams reveal the latitudinal position of each lake within the transect. Populus and Betula levels are greater at Lofty Lake than Mariana Lake through most of the Holocene; both taxa do well in warmer more open conditions which they are more likely to find in the southern Boreal Forest. During the Hypsithermal, however, this lower conifer canopy density shifts northward, and so we see the Populus and Betula become more common at Mariana Lake than Lofty Lake. At Lofty Lake, the herbaceous taxa increase as Lofty Lake becomes Parkland - this, too, is reflected in the difference diagram. During modern times the greater levels of coniferous taxa at Mariana Lake reflects the cooler conditions.

Just as deciduous taxa were greater at Lofty Lake than Mariana Lake because Lofty Lake was farther south, we see the levels of Populus and Betula at Mariana Lake being generally greater than the levels at Eaglenest Lake. For example, the Betula zone occurs at both lakes but it is stronger at Mariana Lake, as seen in the difference diagram. The Picea level at the same time is greater at Eaglenest Lake during the same period. During the Hypsithermal, Populus and Betula are much greater at Mariana Lake, while Sphagnum levels are greater at Eaglenest Lake, reflecting the differences in aridity. Eaglenest Lake is too far from the Parkland ecotone (or, equally correct, the Hypsithermal was not strong enough) for mid-Holocene, Hypsithermal induced vegetational changes to occur.

The differences between Mariana Lake and Wild Spear Lake often reflect the large latitudinal distance between them. The great differences in Picea at the beginning of the core is because Picea has not yet arrived at Wild Spear Lake. Once Picea does establish itself, it accounts for a larger percentage of the vegetational community than at Mariana Lake - this is due to the dominant Picea mariana - Sphagnum muskeg that is located around Wild Spear Lake (MacDonald, 1989) while Mariana Lake can support a more mixed vegetation with its more southern location. Like *Picea mariana*, *Sphagnum* values are virtually always higher at Wild Spear Lake. The effect of the Hypsithermal is reflected in the *Populus* differences between the lakes. *Populus* values are greater at Mariana Lake for most of the Holocene, but this difference is greatest during the Hypsithermal. Wild Spear Lake, like Eaglenest Lake, is too far from the southern forest limits to be significantly affected by the Hypsithermal.

Conclusions

Hypsithermal warming occurred during the mid-Holocene, pushing vegetational boundaries northward. Southern Boreal Forest sites, such as Lofty Lake, became parkland, while sites further north experienced progressively fewer changes, until no Hypsithermal effect is recorded in the pollen record at northern sites; this is the case at Eaglenest Lake and Wild Spear Lake. Mariana Lake, about 225 km north of the present Parkland boundary, was influenced by the Hypsithermal, but did not become parkland. Given the rapid vegetation gradients that occur across the modern ecotone border, the Parkland - Boreal Forest boundary must have approached close to the Mariana Lake region to begin to open up the canopy of the vegetation surrounding the lake as it did. The Hypsithermal peak appears to have occurred between 6 000 and 7 000 yr BP at Mariana Lake.

This is supported by the peatland research of Nicholson and Vitt (1990) who found major peat development near Mariana Lake only occurred after 6 000 yr BP. The declining vegetational effect of the Hypsithermal on the postglacial pollen records of the 4 sites shows the limits to the strength of the Hypsithermal and the resiliency of the Boreal Forest. This first order estimate of the extent of mid-Holocene Parkland advance in Alberta should prove to be a useful contribution to other research.

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