FOREST HISTORY OF THE LAST 12,000 YEARS BASED ON PLANT MACROFOSSIL ANALYSIS OF LAKE SEDIMENT FROM SOUTHWESTERN B.C.

by

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Title of Thesis/Project/Extended Essay

Forest History of the Last 12,000 Years Based on Plant Macrofossil Analysis of Lake Sediment in Southwestern B.C.

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ABSTRACT

The forest history around Marion Lake in southwestern B.C. is reconstructed using plant macrofossil analysis, and compared to a previous reconstruction based on pollen and spore analysis by R.W. Mathewes.

Thirty mud surface samples were collected in order to establish the distribution of modern macrofossils. Conifer needles were more abundant than their seeds, while, for most other taxa, reproductive structures were more common than vegetative ones. Needle fragments of *Pinus monticola* are overrepresented in the sediments. A proportional relationship between the log of the average concentration and the frequency at which macrofossils were encountered suggests a good dispersion within the basin. The sample sites are separated into three groups on the basis of their macrofossil floras; offshore samples, west shore samples and east shore samples.

A sediment core spanning 12,000 years was collected from a site as close as possible to Mathewes' core. The results of macrofossil analysis are presented as a percentage diagram for conifer needles and as an influx diagram for all taxa.

There is good correspondence between macrofossil and pollen zones, although the start of each pollen zone predates its macrofossil analogue. Needles of *Pinus contorta* are found at the base of the core, followed by a period, 11,500 to 9000 B.P., when the only needles encountered are those of *Picea sitchensis*. *Abies amabilis* and *Tsuga heterophylla* needles appear at 9000 B.P., rising to maximum levels by 6600 B.P. The first macrofossils (branchlet units, scale leaves and staminate cone scales) of *Thuja plicata* appear abruptly at 6000 B.P. and rise rapidly to modern levels. A previous report of *Thuja* macrofossils at 10,000 B.P. is likely the result of contamination at a core segment boundary. *Taxus brevifolia* may have been an important component of the forest prior to the arrival of *Thuja plicata*.

Fluvial input of macrofossils is important at Marion Lake. An increase in the total influx coincides with evidence for increased precipitation after 7000 B.P. Marked reductions in influx coincide with periods of peat building upstream from the present lake. The influx of charcoal parallels the input of macrofossils, suggesting that charcoal greater than 250 microns in diameter may enter the lake primarily during periods of high runoff and erosion in the watershed.

DEDICATION

To Kathy, Pam and David.

ACKNOWLEDGEMENTS

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INTRODUCTION

BACKGROUND

Plant macrofossils can be defined as:

> "any part of a plant preserved after death which does not require a high power microscope to see it, and which can be manipulated by hand" (Birks,1980,p.2).

While once the primary source of information available to paleoecologists, plant macrofossils have played a secondary role since the quantitative methods for pollen analysis became well established in the late 1930's and 1940's (Watts,1978). Macrofossils have been used to supplement pollen data by

1) establishing the local presence of taxa whose pollen or spores are known to travel great distances,

2) providing positive identification, usually to the species level, for taxa whose pollen can only be identified to the Family or Genus level

and

3) providing evidence of taxa whose pollen is rarely found or is not found at all, as is the case with many insect-pollinated species.

More recently it has become common practice, when analyzing a sediment core, to section the core and extract and count the macrofossils in each section. The results are often presented in the form of a macrofossil diagram that is analagous to the diagrams produced using pollen data.

The first quantitative plant macrofossil study in North America was produced by Watts and Winter in 1966. They presented their data as a percentage of the total seed sum, thus emphasizing the relative abundance of the various macrofossils. The problem with this method of presentation is that an increase in one taxon reduces the apparent importance of other taxa, even though their macrofossils may be as abundant as ever. More recent studies, by Delcourt (1980) and Watts (1979), for example, have tended to present the macrofossil data as concentrations, usually macrofossils per 100 ml of sediment. Others, such as Birks and Mathewes (1978) and Delcourt (1979), have presented their data as a macrofossil influx; the number of macrofossils deposited per unit area per year.

Regardless of how the data are presented, the problem remains that, for plant macrofossils, the relationship between the number of macrofossils found and the abundance of the 'parent' plant is not well established. For example, if a large number of Thuja plicata needles are found in a core, was the tree abundant in the forest, or, was there a tree growing near to the coring site? Establishing the relationship between fossils and the community that produced them is within the realm of taphonomy (Lawrence,1971). A number of recent studies have attempted to establish this relationship for plants in an effort to better interpret the macrofossil data.

Some authors have concentrated on the means of transport to the deposition site, since macrofossils have typically been used to 'prove' local presence of a taxon. Glaser (1981) found that, in a treeless snow-covered landscape, leaves and seeds could be blown beyond the vegetational zones in which they originated. Bonde (1969) found wind to be a significant means of dispersal for vegetation of alpine areas. Rydvarden (1971) found that rivers and streams may carry macrofossils for long distances, especially those macrofossils with good buoyancy. Burrows (1980) found evidence of the long distance transport of leaves by streams from as much as three kilometers away. These studies question the assumption of local presence of a taxon based upon the presence of its macrofossils in the sediments.

Other authors have sought to establish a relationship between the concentration of macrofossils in surface sediments and the composition of the surrounding vegetation. McQueen (1969,p.18) found at lake Pounui in New Zealand that:

> "plant remains in a densely vegetated swamp were almost exclusively of plants growing in or near the swamp"

and further that:

> "in the lake sediments the plant remains represented only the dominant members of the vegetation surrounding the lake".

Birks (1973) demonstrated that lakes in the prairie, deciduous forest and coniferous forest regions of Minnesota could be characterized by the macrofossil floras of their surface sediments. Drake and Burrows (1980) found there was good qualitative representation of forest trees in the lake litter of Lady Lake in New Zealand and for some species there was also good quantitative representation. Greatrex (1983) found, for some species, there was a general relationship between cover-abundance and seed-representation in surface sediment samples in a small eutrophic lake in England. Dunwiddie (1983), in a study of surface sediment samples from a series of ponds on Mount Rainier in Washington, found a statistically significant relationship between tree basal area and needle macrofossils for most conifers. These and other studies have encouraged the use of plant macrofossils not only as a supplement to pollen but as *bona fide* tools in their own right.

AIMS AND OBJECTIVES

While some authors have produced macrofossil diagrams to supplement their pollen data and others have studied various aspects of the taphonomy of plant macrofossils, few have used a study of macrofossils in surface sediments to aid in the interpretation of a macrofossil diagram from the same site. The objectives of this study were:

1) to compare the distribution and abundance of plant macrofossils in the surface sediments of Marion Lake with the vegetation and topography of the drainage basin,

2) to reconstruct the vegetational history of the Marion Lake basin by analyzing the macrofossils in a sediment core, using the results of the surface sample study to aid in the analysis

and

3) to compare the vegetation history based on macrofossil analysis with that of a previous study (Mathewes,1973) based on pollen analysis.

Of special interest was the early history of Thuja plicata (western red cedar). Mathewes (1973) reported the surprising occurrence of Thuja macrofossils at Marion Lake about 10,000 years B.P., although the pollen data did not record significant Cupressaceae until after about 6600 years B.P. The validity of this early occurrence of Thuja would be tested by a more detailed macrofossil analysis.

THE STUDY AREA

Marion Lake is located within the University of British Columbia Research Forest about 40 km east of Vancouver. The forest is within the Coast Mountains of British Columbia, and, although the topography is variable, in excess of 80% of the area is hilly to mountainous. Elevations range from 250 to 790 meters. The bedrock underlying the area is mainly granodiorite and quartz diorite covered by glacial till and outwash deposits of variable thickness (Lacate,1965). The climate of the area is designated by Koppen as Cfb. It is characterized by wet mild winters and relatively dry summers. Average annual precipitation at Marion Lake is about 300 cm per year with over 80% of the total falling between October and April.

The lake lies in a valley at an elevation of 300 meters in the transition between the dry and wet subzones of the Coastal Western Hemlock (CWH) biogeoclimatic zone (Klinka,1976). The lake is 800 meters long and 200 meters wide at its widest point, covering an area of 13.3 hectares. Mean depth is about 2 meters with a maximum depth of about 5 to 7 meters depending upon the time of year. Jacob's Creek feeds the lake from a drainage basin of about 13 square kilometers. Within this basin there are two other lakes above Marion Lake. During heavy rainfall the lake level has been observed to rise as much as 1 meter in 24 hours and the equivalent total volume of the lake may be flushed out in 2.3 days (Efford,1967). This has been attributed to the combination of permeable soils overlying an impermeable basal till and to the extreme relief of the area.

PART B

THE SURFACE SEDIMENT STUDY

CHAPTER I

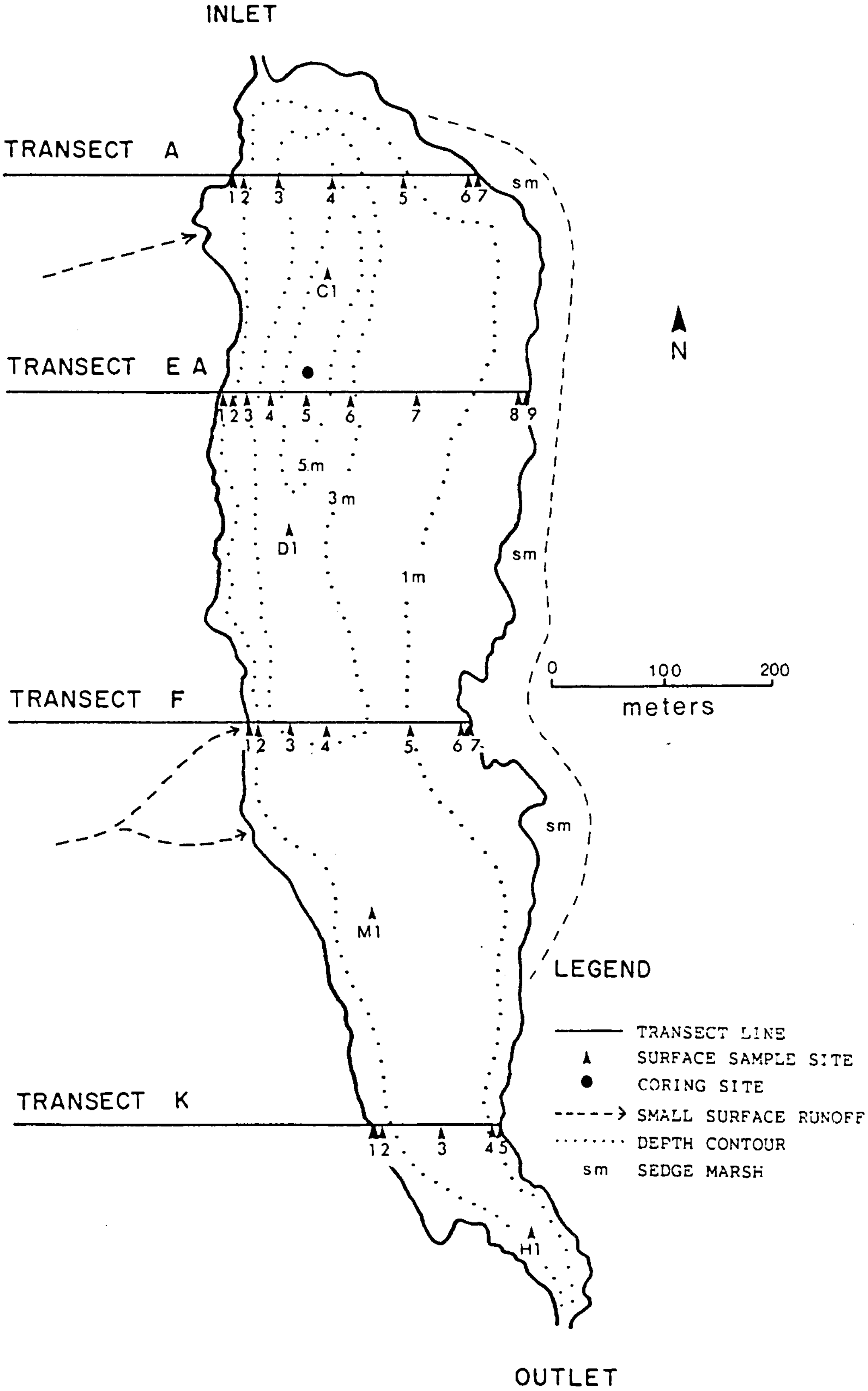
METHODS

FIELD METHODS

In July 1982 a series of surface-sediment samples were taken from Marion Lake. The samples were collected from a boat using a 15 by 15 cm Ekman dredge. In order to obtain samples of about 400 ml, the top few cm of each 'grab' were spooned into a graduated beaker and then placed into self-sealing plastic bags.

The sampling points were located on four west/east transects across the lake, and also in the channel that runs from the inlet almost to the outlet (Figure 1). The transects were positioned and named relative to the grid markers left by the International Biological Programme study that was ongoing at Marion Lake from 1962 to 1973 (Efford and Hall,1975). Nearshore samples were taken systematically one meter and five meters from the shoreline on each end of a transect. Offshore samples were taken at intervals so as to have at least one sample from the deepest part of the lake along each transect. Additional samples, not on the transects, were taken from the deep channel. The sample sites on each transect are named after their transect and numbered consecutively from west to east. The other sites are named for the letter of the nearest I.B.P. marker.

Figure 1. Outline of Marion Lake showing the locations of the sample sites.


INLET
TRANSECT A
1 2 3 4 5 6 7
sm
C1
TRANSECT E A
1 2 3 4 5 6 7 8 9
5m
3m
D1
1m
sm
N
0 100 200
meters
TRANSECT F
1 2 3 4 5 6 7
sm
M1
LEGEND
TRANSECT LINE
SURFACE SAMPLE SITE
CORING SITE
SMALL SURFACE RUNOFF
DEPTH CONTOUR
sm SEDGE MARSH
TRANSECT K
1 2 3 4 5
H1
OUTLET

LABORATORY METHODS

Sample Manipulation

The bulk density of each surface sediment sample was determined by weighing the whole sample and determining its volume by displacement in a graduated cylinder containing a known volume of water. The dry weight and loss on ignition were determined by the method of Bengtsson (1979). To determine the dry weight, 5 cc sediment subsamples, taken with a plastic syringe, were left overnight in a drying oven at 105 degrees C. To determine the loss on ignition, the dried subsamples were placed in a muffle furnace for 2 hours at 540 degrees C.

To facilitate the job of picking out macrofossils, sediment samples were screened under running water using a 250 micron (60 mesh) sieve. The debris that did not pass through the sieve, hereafter referred to as 'residue', was stored in 70 percent alcohol. Because of unforeseen large volumes, it became necessary to subsample the residue prior to picking out macrofossils. In order to prevent a few large macrofossils from interfering with the subsampling procedure, each residue sample was first subdivided into a large and a small diameter fraction using a 2 mm (9 mesh) sieve. The wet volume of each small diameter fraction was determined by displacement using a graduated cylinder. Where the volume of a small diameter fraction exceeded 15 ml, a subsample was taken by the following method: The residue was spread out on a 250 micron mesh using jets of water from a 'shower type' faucet. Using a spatula, scoops of wet residue were added to water in a graduated cylinder to yield a displacement volume of 10ml.

The wet volume of each large diameter fraction of the residue was also measured in order to look at the distribution of residue volumes within the lake.

Picking and Sorting

The residue samples were picked over for macrofossils using a stereoscopic microscope. Identifiable plant macrofossils were picked out using forceps and stored in drops of glycerine in plastic trays, or, where numbers warranted, in vials of 70% alcohol. The primary interest was in plant macrofossils of forest species. However, all seeds and fruits were picked, as were bryozoan statoblasts, Chara and Nitella oospores, Isoetes megaspores and pieces of charcoal. Where possible, macrofossils were identified by comparison with modern reference material. The convention used in assigning a taxon is that of Watts and Winter (1966). Plant nomenclature follows Taylor and MacBryde (1977).

Counting

Since many macrofossils, especially conifer needles, were fragmented (Plate I-4), the following counting strategy was adopted:

1) where a whole needle was encountered it was counted as one,

2) where an identifiable tip or base of a needle was encountered it was also counted as one,

3) where an unidentifiable tip or base was encountered it was counted as an unknown,

4) all portions of needles without the tip or the base were ignored,

and

5) for fruits, seeds and other macrofossils any portion that represented half or more of the original was counted as a whole.

The counting of Pinus monticola needle fragments (Plate I-5) presented a special problem because most of the fragments were missing both tip and base. In this case, the length, in millimeters, of each fragment was measured and the total length in cm recorded.

Where a 10 ml subsample was taken from a small diameter fraction of the residue, the numbers of macrofossils counted were scaled up as follows:

$$\text{Scaled no.} = \frac{\text{no. in 10 ml subsample x vol. of fraction (ml)}}{\text{10 ml}}$$

For each macrofossil type in each sample, the concentration per 100 ml of sediment was calculated as follows:

$$C = \frac{(L + S)\,100}{V}$$

where: C = concentration per 100 ml
L = total number in large diameter fraction
S = total number in small diameter fraction
V = volume of sediment sample (ml)

CHAPTER II

RESULTS AND DISCUSSION

THE SAMPLES

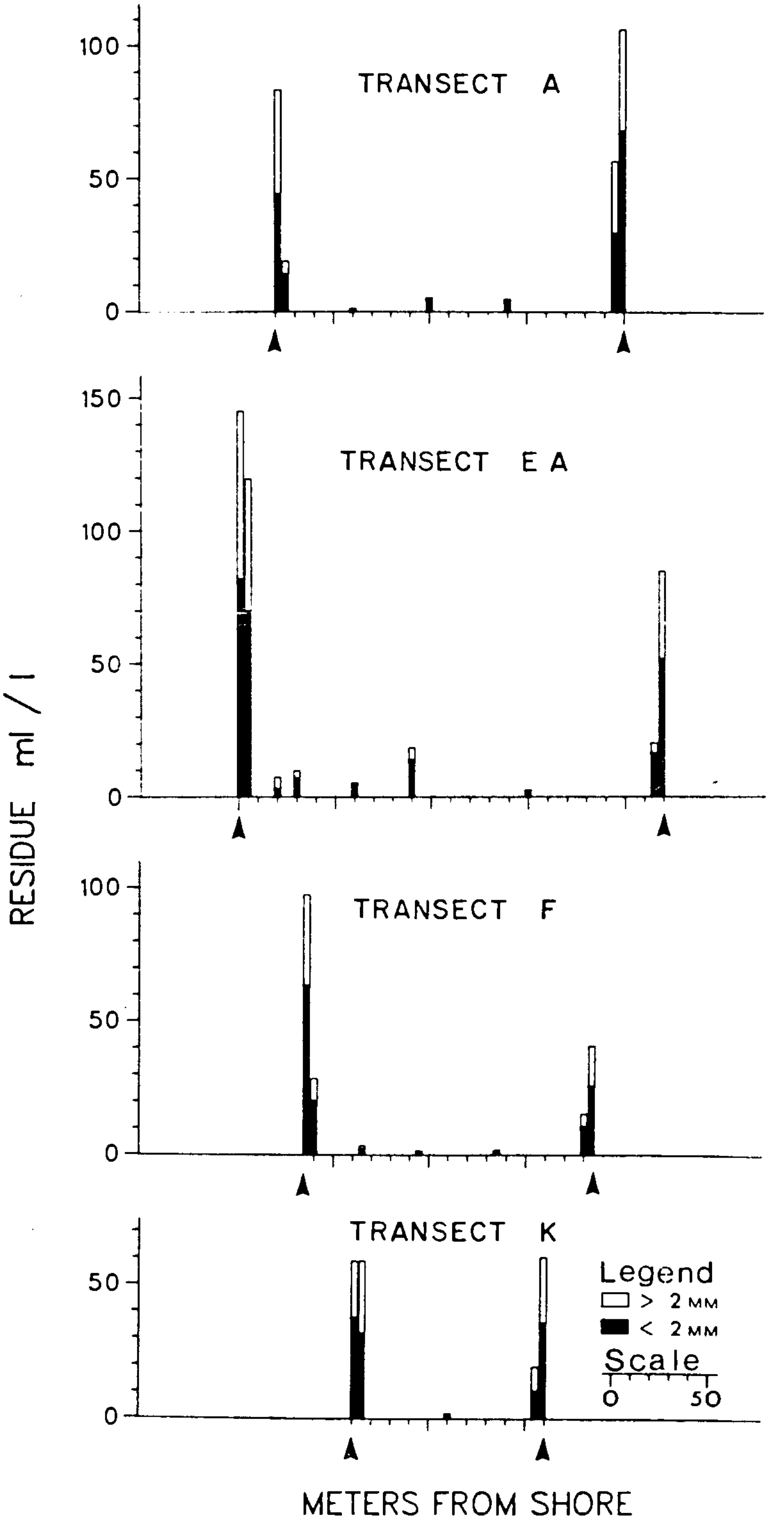
Similar volumes were used for the surface sediment samples and all have similar bulk densities (Table 1). However, the nearshore samples, collected 1 and 5 meters from shore, have both lower dry weights and higher losses on ignition than the offshore samples, collected 20 or more meters from shore. Mean dry weights were 65.1 ± 18.9 g (per kg of wet residue) for nearshore and 75.5 ± 15.2 g for offshore samples. Loss on ignition averages were 53.5 ± 15.5 % of dry weight for nearshore and 27.2 ± 6.75 % of dry weight for offshore samples. Using a Mann-Whitney two-sample rank test, the difference in loss on ignition between nearshore and offshore samples was statistically significant ($p<0.0001$). The differences in dry weight ($p<0.1$) and bulk density ($p>0.1$) where not significant.

The high losses on ignition and the low dry weights of the nearshore surface sediment samples are due to an abundance of plant litter in these samples. Here most of the residue is plant litter with only trace amounts of sand. This preponderance of litter in the nearshore samples can be seen along each transect (Figure 2). The difference is even more pronounced for the large diameter fraction of the residue than for the small diameter fraction, suggesting a nearshore bias towards larger litter. This distribution of residue was statistically significant for both the large and small diameter

Table 1. Volume of residue, bulk density, dry weight, and loss on ignition for each of the surface sediment samples. (S.D. = standard deviation, * = samples were not obtained due to the accumulation of debris on the bottom of the lake)

SITE	DISTANCE TO NEAR SHORE (m)	DEPTH (m)	VOLUME (ml)	B.D. (kg/l)	D.W. (g)	L.I. (%D.W.)
NEARSHORE SAMPLES						
A1	1	0.10	428	1.03	53.8	58.4
A2	5	0.50	378	1.03	61.8	35.9
A6	5	0.25	449	1.01	43.3	55.0
A7	1	0.05	437	1.01	38.4	68.2
EA1	1	0.05	400	1.04	72.0	80.7
EA2	5	0.35	420	1.04	71.7	53.1
EA8	5	0.30	388	1.04	40.9	62.3
EA9	1	0.05	381	1.02	62.9	80.1
F1	1	0.20	369	1.05	98.9	60.7
F2	5	0.80	370	1.03	109	44.7
F6	5	0.10	404	1.03	64.7	31.4
F7	1	0.05	394	1.01	70.5	38.1
K1	1	0.20	403	1.03	73.4	48.5
K2	5	0.50	348	1.04	52.6	61.8
K4	5	0.20	406	1.04	63.4	31.1
K5	1	0.10	399	1.01	64.0	45.4
MEAN		0.238	398	1.03	65.1	53.5
S.D.		0.205	25.7	.013	18.9	15.5
OFFSHORE SAMPLES						
A3*	40	2.00	-	-	-	-
A4	80	5.40	411	1.07	101	40.0
A5	60	1.12	386	1.03	65.1	23.6
EA3	20	1.57	397	1.03	57.9	20.3
EA4	30	2.53	439	1.05	84.0	31.5
EA5	60	4.37	375	1.05	94.7	36.4
EA6	90	3.40	397	1.09	84.7	30.8
EA7	70	1.40	354	1.03	72.5	26.2
F3	30	3.20	387	1.03	59.4	22.7
F4	60	3.30	382	1.01	73.5	28.1
F5	50	1.75	378	1.04	66.9	25.6
K3	50	1.28	356	1.03	84.0	19.1
C1*	60	5.42	-	-	-	-
D1	50	3.90	363	1.04	95.8	35.9
M1	50	1.82	390	1.03	55.5	20.3
H1	25	1.50	396	1.03	61.8	20.9
MEAN	51.6	2.75	387	1.04	75.5	27.2
S.D.	18.8	1.39	21.5	.019	15.2	6.75

Figure 2. Distribution of screened residue volumes along the four sample transects in the lake. The nearshore samples had consistently greater volumes of residue than the offshore samples. This was especially true for the large diameter (greater than 2mm) fraction of the residue. Arrowheads indicate shore.


TRANSECT A
0
50
100
TRANSECT E A
0
50
100
150
TRANSECT F
0
50
100
TRANSECT K
0
50
Legend
□ > 2 MM
■ < 2 MM
Scale
0
50
RESIDUE ml / l
METERS FROM SHORE

fractions ($p<0.0001$).

The statistically significant abundance of plant litter in the nearshore samples supports the findings of other authors. Gasith and Hasler (1975), in their study of airborne litterfall into lakes, found that for most lakes the input of litter at a distance of 10 meters from shore was less than 10 percent of the input 1 meter from shore. Similarly, Odum and Prentki (1978), in their study of 5 North American lake ecosystems, found that litter input to the lakes was proportional to the length of their forested shorelines. It is clear from the foregoing that distance from shore is expected to be a major factor in the distribution patterns of at least some of the macrofossil taxa.

THE MACROFOSSILS

Concentration and Frequency

Forty different macrofossils were encountered in the surface samples. Site frequencies and average concentrations for those macrofossils found at 5 or more sites are given in Table 2. The site frequency is simply the number of sites at which a macrofossil was encountered. Only those macrofossils found at five or more sites are included, as fewer than five occurrences could not have been significant using non-parametric statistical tests. Zero values were not included in the calculation of average concentrations, so the averages reflect the numbers to be expected at sites where the macrofossils do occur.

Table 2. Average concentration and frequency of occurrence for those macrofossils found at five or more sites. Zero values were not included in the calculations, so the concentrations reflect the numbers to be expected at sites where the macrofossils do occur.

MACROFOSSIL	SITE FREQUENCY	AVERAGE CONCENTRATION (no./100ml)
THUJA PLICATA scale leaves	30	304
branchlet units	29	158
male cone scales	28	17.6
MONOCOT 'node plates'	27	6.7
UNKNOWN discs	26	4.8
PINUS MONTICOLA needles (cm)	25	9.5
TSUGA HETEROPHYLLA needles	24	6.9
JUNCUS sp. seeds	22	21.6
CAREX sp. achenes	20	14.3
RUBUS SPECTABILIS/PARVIFLORUS seeds	19	2.8
MYRICA GALE bud scales	17	9.2
ERICACEAE seeds	15	1.9
TSUGA HETEROPHYLLA pollen sacs	15	1.5
THUJA PLICATA seeds	13	1.1
NAJAS FLEXILIS seeds	13	1.0
CRISTATELLA cf. MUC. statoblasts	12	2.5
ISOETES cf. LACUSTRIS megaspores	12	1.5
MYRICA GALE seeds	12	1.0
UNKNOWN ANIMAL 'sacs'	11	0.5
ABIES AMABILIS needles	10	0.9
MENYANTHES TRIFOLIATA seeds	9	1.4
DULICHIUM ARUNDINACEUM achenes	9	1.2
NITELLA sp. oospores	7	6.7
PHYSOCARPUS CAPITATUS seeds	7	3.3
UNKNOWN 'pollen sacs'	7	2.6
ALNUS RUBRA seeds	7	2.2
TSUGA HETEROPHYLLA seeds	7	0.5
PSEUDOTSUGA MENZIESII needles	6	1.1
NUPHAR LUTEA subsp. POLYSEPALA seeds	5	0.5

For plant macrofossils, the relationship between the log of the average concentration and the site frequency is linear (Figure 3). For vegetative macrofossils,

$$\log [\text{ AVE. CONC. }] = -0.534 + 0.0734 \text{ SITE FREQUENCY}$$

for reproductive macrofossils,

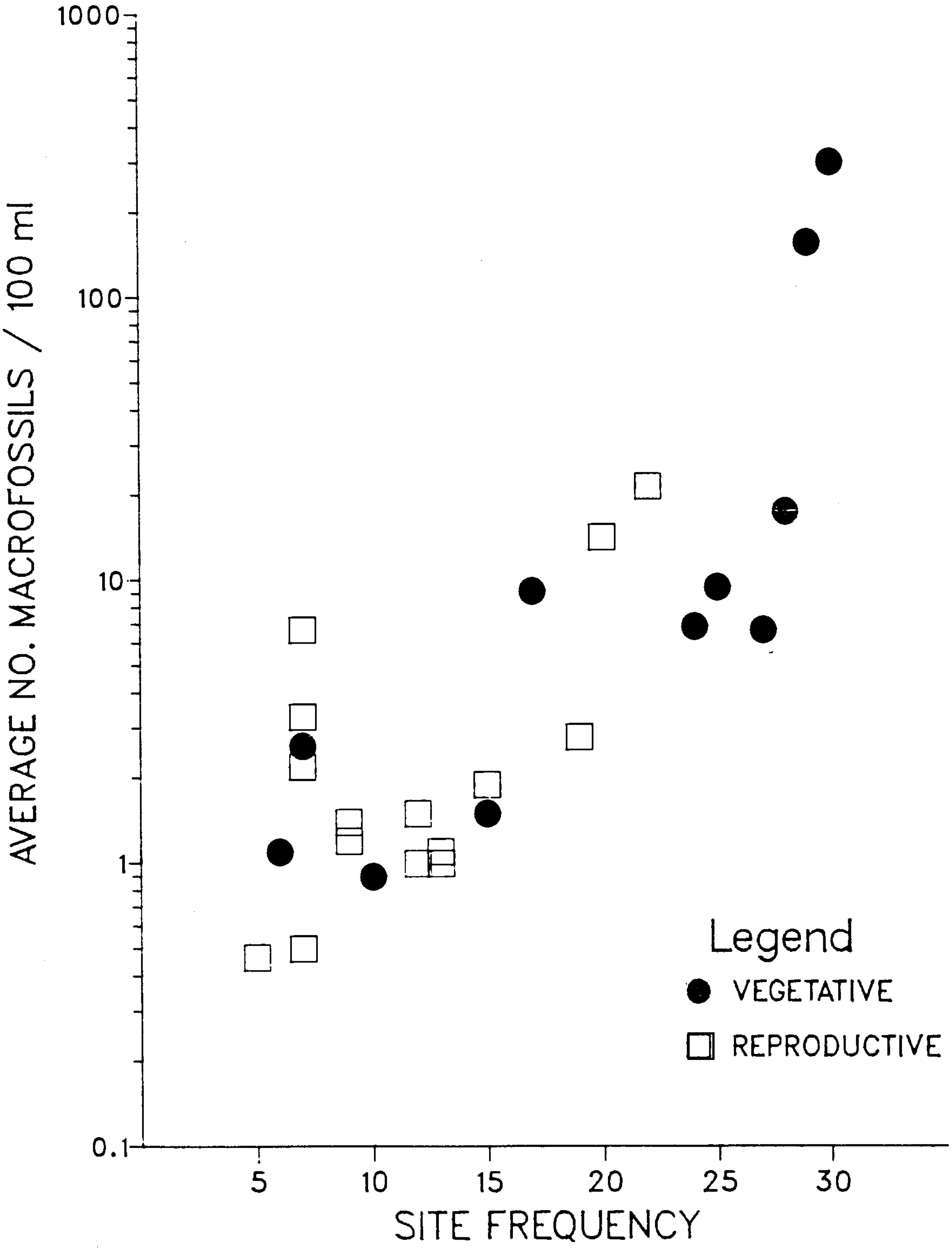
$$\log [\text{ AVE. CONC. }] = -0.352 + 0.0580 \text{ SITE FREQUENCY.}$$

The fit is somewhat better for vegetative macrofossils ($r^2=0.668$) than for reproductive ones ($r^2=0.417$). The regressions are significant ($p<0.005$, vegetative; $p<0.01$, reproductive). Reproductive macrofossils are those parts of the plant normally dispersed for the purpose of reproduction, such as seeds, fruits, megaspores and oospores. All other macrofossils, including bud scales, male cones scales and pollen sacs, are considered to be vegetative.

One of the critical questions in the analysis of macrofossil data is to what extent macrofossils are dispersed from the point of origin. Birks (1973) showed macrofossils are not well dispersed in a series of small lakes in Minnesota. If macrofossils are not well dispersed one would expect at least some of the macrofossils found at only a few sites to be present at high concentrations.

In my own study, as can be seen from the linear relationship between the log of the average concentration and the site frequency, those macrofossils found at high concentrations were found at most sites. With the exception of Nitella oospores, all macrofossils found at average concentrations in excess of 5 per 100 ml were found at more than half the sites. Even Tsuga pollen sacs, found at an average concentration of only 1.46 per 100 ml, were found at half the sites.

Figure 3. Average concentration vs site frequency for those plant macrofossils found at five or more sites. The frequency is proportional to the log of the average concentration. The fit is somewhat better for vegetative macrofossils (shaded circles,r^2=66.8) than for reproductive ones (open squares,r^2=41.7).


AVERAGE NO. MACROFOSSILS / 100 ml
1000
100
10
1
0.1
5
10
15
20
25
30
SITE FREQUENCY
Legend
● VEGETATIVE
□ REPRODUCTIVE

It is not surprising that macrofossils found at average concentrations less than 0.5 per 100 ml were less frequently encountered given that the average sample size was only 400 ml. Macrofossils found at fewer than five sites never exceeded an average concentration of 2.8 per 100 ml and most were less than 1 per 100 ml. Thus it seems macrofossils are well dispersed in Marion Lake.

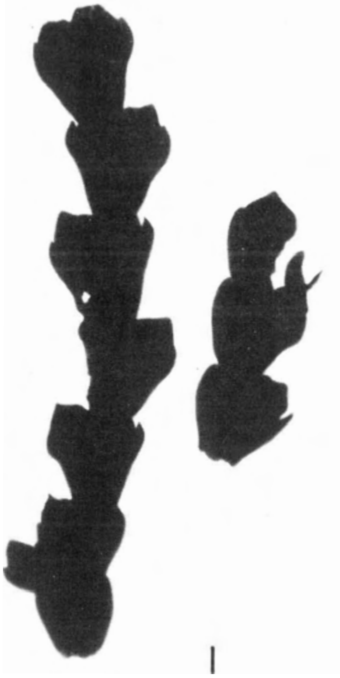
Vegetative and Reproductive Macrofossils

Vegetative macrofossils were found at significantly greater average concentrations ($p<0.05$, Mann-Whitney test) and at significantly more sites ($p<0.025$) than reproductive ones. Most of this difference can be attributed to a preponderance of vegetative macrofossils of the forest trees as compared to their seeds (Table 2). Despite the occurrence of vegetative Thuja plicata macrofossils at all sites at an average concentration of 300 per ml, Thuja seeds were found at only 13 of the 30 sites at an average concentration of 1 per ml. Tsuga heterophylla needles were found at 24 sites at an average concentration of 7 per ml while Tsuga seeds were found at only 7 sites at an average concentration of 0.5 per ml. Similarly, needles of Pinus monticola, Abies amabilis and Pseudotsuga menziesii were found at 25, 10 and 6 sites respectively while the seeds of these species were found at fewer than 5 sites.

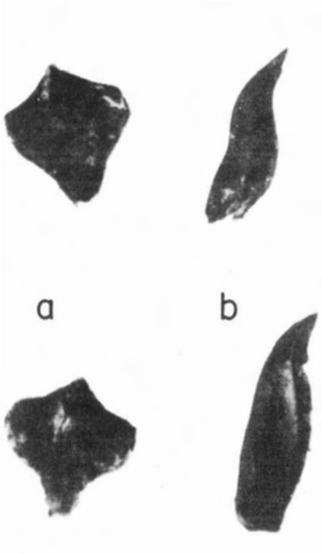
The three most frequently encountered and most abundantly found macrofossils are vegetative fragments of Thuja plicata. Thuja branchlets (Plate I-1) are made up of scale leaves (Plate I-2,a and b) arranged in four rows. Although some of the scale leaves resulted from

Plate I. 1-3; Thuja plicata macrofossils; 1-branchlet units (x6); 2-scale leaves (x8), a-middles, b-sides; 3a-male cone (x16), 3b-male cone scale (x16); 4-Abies amabilis needles (x4); 5-Pinus monticola needles (x2).

PLATE I



1



2

3

4

5

the break-up of branchlet units during processing, many were observed in the sediments prior to screening. Scale leaves were found at all sites and branchlet units at 29 of the 30 sites. Thuja male cones (Plate I-3a) are made up of several scales (Plate I-3b) which were found at 28 of the 30 sites.

Figure 4 shows the distribution of Thuja macrofossils along the four transects across the lake. They are more abundant in the nearshore sites than offshore, and more abundant in the west shore than in the east shore sites. The only offshore sites with appreciable concentrations of these macrofossils were those along transects A and EA adjacent to the main inlet stream. This suggests that many Thuja macrofossils enter the lake through fluvial transport. Attempts to take surface sediment samples at sites A3 and C1 were unsuccessful due to the abundance of debris, including many Thuja branchlets, which prevented the jaws of the Ekman dredge from closing properly.

Since the surface sediment residue consists mostly of plant debris, the abundance of Thuja in the nearshore sites could be expected from the abundance of total residue at these locations. However, the abundance of Thuja in the west shore sites was unexpected, since there was no significant difference in residue volume between the two shores. The sorting of macrofossils within the lake is more complicated than just the nearshore/offshore dichotomy suggested by the residue volumes.

The origin of the fourth most frequently encountered macrofossils is uncertain, although they may be 'node plates' from monocot stems

Figure 4. Distribution of <u>Thuja</u> macrofossils along the four sample transects across the lake. There were more macrofossils in the nearshore sites than offshore, and more in the west shore sites than in the east shore sites (note changes in scale, arrowheads indicate shore) See Figure 1 for the transect locations.

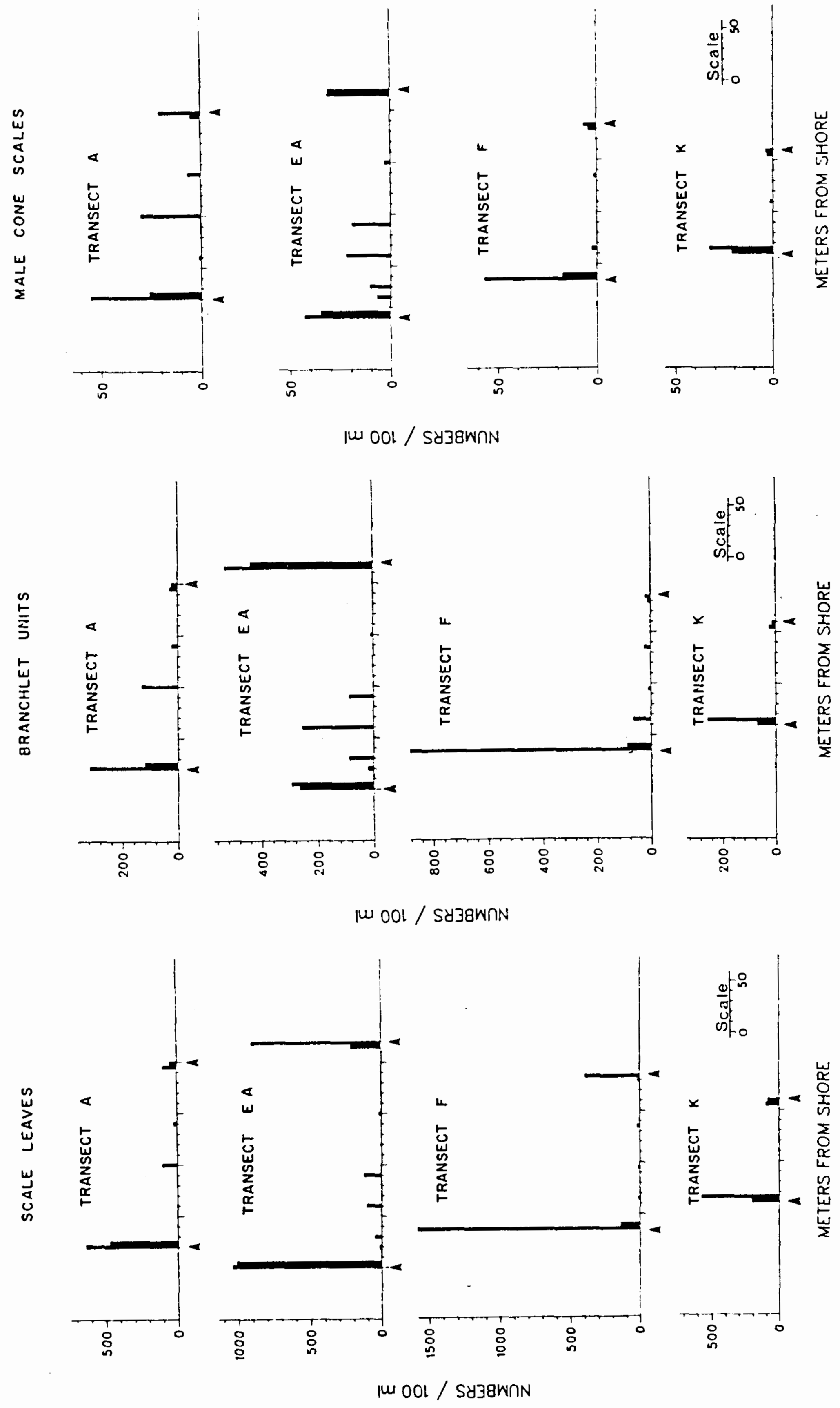
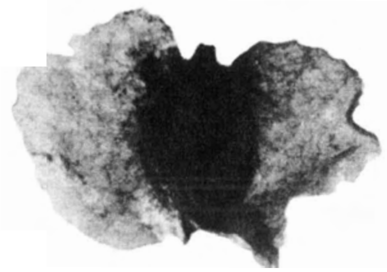

SCALE LEAVES
TRANSECT A
500
0
TRANSECT E A
1000
500
0
TRANSECT F
1500
1000
500
0
TRANSECT K
500
0
Scale
0
50
METERS FROM SHORE
NUMBERS / 100 ml
BRANCHLET UNITS
TRANSECT A
200
0
TRANSECT E A
400
200
0
TRANSECT F
800
600
400
200
0
TRANSECT K
200
0
Scale
0
50
METERS FROM SHORE
NUMBERS / 100 ml
MALE CONE SCALES
TRANSECT A
50
0
TRANSECT E A
50
0
TRANSECT F
50
0
TRANSECT K
50
0
Scale
0
50
METERS FROM SHORE
NUMBERS / 100 ml

Plate II. Assorted seeds, fruits and achenes: 1-*Alnus rubra* (x8); 2-*Betula papyrifera* (x8); 3-*Physocarpus capitatus* (x12); 4-*Rubus* (x12), a-*parviflorus*, b-*spectabilis*; 5-*Myrica gale* (x12), a-fruit, b-fruit with bractlets; 6-*Ericaceae* (x16), a-*Vaccinium* sp., b-*Gaultheria shallon*; 7-*Juncus* sp. (x24); 8-*Carex* sp. (x8); 9-*Dulichium arundinaceum* (x6); 10-*Menyanthes trifoliata* (x12).

PLATE II

1



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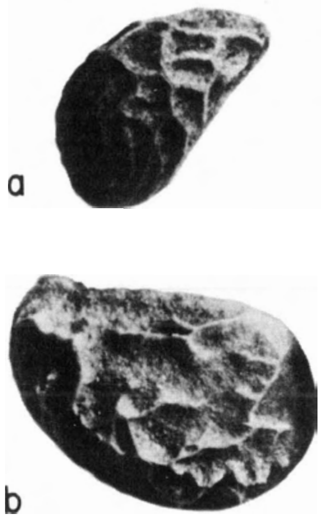

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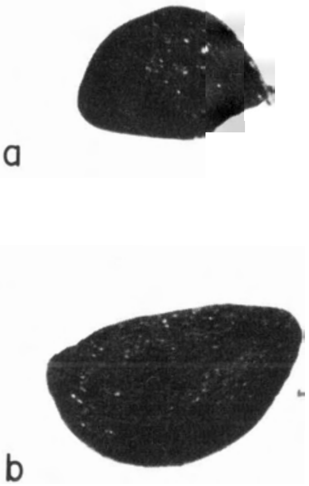

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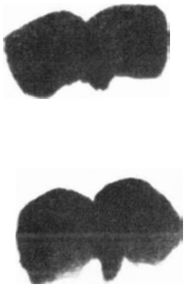
Plate III. 1-*Nitella* sp. oospores (x24); 2-*Chara* sp. oospores (x24); 3-*Isoetes* cf. *lacustris* megaspores (x36); 4-*Tsuga heterophylla* pollen sacs (x12); 5-*Myrica gale* bud scales (x12); 6-Monocot 'node plates' (x24); 7-tiny discs (x24); 8-Bryozoan statoblasts (x12), a-*Fredricella* sp., b-*Cristatella* cf. *mucedo*; 9-Unknown animal 'sacs' (x4).

PLATE III


1


2


3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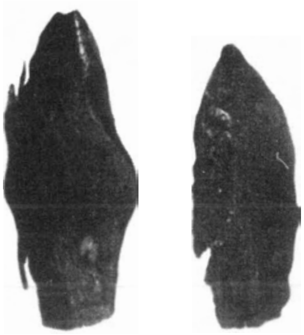
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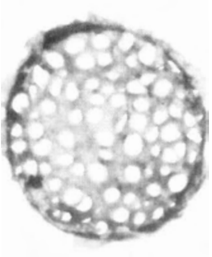
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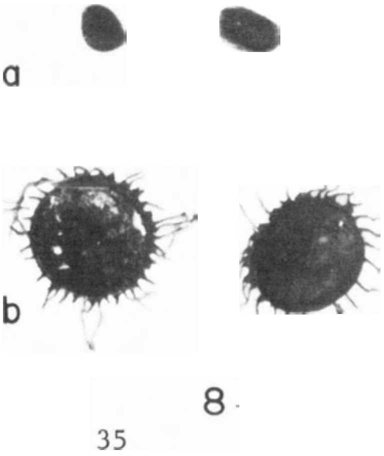

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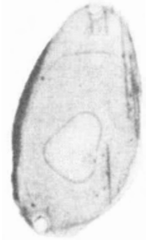
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(Plate III-6). The fifth most frequently encountered macrofossils are small black discs referred to in the tables as 'unknown discs' (Plate III-7). The discs are most likely of animal origin, perhaps egg cases, as there was no apparent placental attachment as might be expected with seeds. Next to branchlets of Thuja plicata the most frequently encountered conifer leaves are needle fragments of Pinus monticola (Plate I-5) and needles of Tsuga heterophylla, found at 25 and 24 sites respectively.

The preponderance of coniferous vegetative macrofossils can be contrasted with the preponderance of reproductive macrofossils of other taxa. With the exception of the 'node plates' and Myrica gale bud scales (Plate III-5), the macrofossils of all other taxa were reproductive structures. A representative sample of these reproductive structures are shown in Plates II and III. The dichotomy between the forest conifers and the other taxa is probably due to the good preservation of conifer leaves compared to leaves of other taxa (Dunwiddie,1983; Drake and Burrows,1980).

Nearshore vs Offshore Comparisons

The nearshore skew seen in the distribution of residue volumes and in the distribution of Thuja macrofossils is a pattern that is repeated for many other macrofossils (Table 3). A few macrofossils are lumped together into higher taxonomic groups. Seeds from berries of Vaccinium ovalifolium , Vaccinium parvifolium and Gaultheria shallon were encountered (Plate II-6,a and b). Individually, none of these seeds are found frequently enough for their distributions to be

Table 3. Nearshore / offshore ratios for those macrofossils found at five or more sites. The ratios were calculated by dividing a taxon's average concentration in the nearshore sites by its average concentration in the offshore sites. The macrofossils are listed in order of the statistical significance of their distributions as calculated by a Mann-Whitney two sample rank test. Where the significance is equal they are listed in order of their nearshore/offshore ratios. Only those distributions with a probability < 0.05 are considered to be statistically significant. (*=there were no macrofossils found in the offshore sites so the ratio could not be calculated)

MACROFOSSIL	RATIO	SITE FREQUENCY	STATISTICAL SIGNIFICANCE
RUBUS sp. seeds	42.2	19	< 0.0001
THUJA PLICATA scale leaves	15.6	30	< 0.0002
CAREX sp. achenes	37.6	20	< 0.0005
MYRICA GALE bud scales	13.1	17	< 0.002
PINUS MONTICOLA needles (cm)	7.0	25	< 0.003
ERICACEAE seeds	4.7	15	< 0.003
THUJA PLICATA male cone scales	3.6	28	< 0.003
THUJA PLICATA branchlet units	4.7	29	< 0.01
JUNCUS sp. seeds	71.7	22	< 0.03
TSUGA HETEROPHYLLA needles	2.2	24	< 0.1
NUPHAR LUTEA subsp. POLY. seeds	*	5	
PHYSOCARPUS CAPITATUS seeds	77.4	7	> 0.1
DULICHIUM ARUNDINACEUM achenes	37.1	9	> 0.1
MENYANTHES TRIFOLIATA seeds	19.0	9	> 0.1
MYRICA GALE seeds	5.3	12	> 0.1
THUJA PLICATA seeds	3.5	13	> 0.1
TSUGA HETEROPHYLLA pollen sacs	2.9	15	> 0.1
CRISTATELLA cf. MUC. statoblasts	2.8	12	> 0.1
TSUGA HETEROPHYLLA seeds	2.4	7	> 0.1
NAJAS FLEXILIS seeds	2.0	13	> 0.1
PSEUDOTSUGA MENZIESII needles	1.8	6	> 0.1
ABIES AMABILIS needles	1.3	10	> 0.1
ISOETES cf. LACUSTRIS megaspores	1.1	12	> 0.1
ALNUS RUBRA seeds	0.8	6	> 0.1
NITELLA sp. oospores	0.1	7	> 0.1
RESIDUE VOLUME > 2mm diameter	27.8	-	< 0.0001
RESIDUE VOLUME total	13.1	-	< 0.0001
RESIDUE VOLUME < 2mm diameter	9.7	-	< 0.0001

statistically significant. Since they are all heath shrubs with seeds of similar size and shape, their macrofossils were tallied as Ericaceae. Similar groupings were made for species of Rubus, Juncus and Carex (Plate II, 4a and b, 7 and 8).

The most statistically significant differences occur where the macrofossil is found at many sites, and where its nearshore/offshore ratio is highly skewed. The distributions of those macrofossils found at only a few sites are not statistically significant even when the nearshore/offshore ratios are highly skewed. For example, although the nearshore/offshore ratio for Physocarpus capitatus seeds (Plate II-3) is 77.4 to 1, the difference in seed abundance between the shores is not significant ($p>0.1$) because the seeds were found at only 7 sites. On the other hand, the difference for Thuja scale leaves is highly significant ($p<0.0002$), even though the nearshore/offshore ratio is only 15.6 to 1, because the scale leaves were found at all thirty sites.

Nearly all macrofossils are more abundantly found in the nearshore samples than in the offshore samples. Conspicuous in the group whose nearshore/offshore distributions are statistically different are Rubus, Carex, Ericaceae and Juncus. The local representatives of these taxa tend to produce seeds and fruits that have limited dispersal by wind. The coniferous macrofossils with the most significantly skewed nearshore/offshore distributions are the smallest ones, Thuja plicata scale leaves and male cone scales and Pinus monticola needle fragments.

The only macrofossils more abundantly found in the offshore samples than in the nearshore samples are seeds of Alnus rubra and oospores of the aquatic alga Nitella. In the case of Nitella, it is not surprising that there should be as many or more macrofossils in the offshore sites as in the nearshore sites. In the case of Alnus however, it is likely that many seeds enter the lake via Jacob's Creek, the main inlet stream. Alnus can be found growing along Jacob's Creek and its tributaries while few were encountered in a survey of the lake margin.

West Shore vs East Shore Comparisons

Although there is no significant difference in screened residue volume between the two shores, there was a significant difference in the distribution of some macrofossils. The macrofossils with the most significantly skewed west shore distributions are those of trees and shrubs (Table 4). The preponderance of forest macrofossils on the west shore can be explained by the topographic differences between the two shorelines. The west slope is steep and in most places the forest extends almost to the shore. It is likely that many macrofossils fall directly into the lake and that many others are washed down the slope during periods of heavy rain. The east slope, on the other hand, is not so steep and there is a sedge mat along most of its length. In some places the forest is up to fifty meters from shore. Here it is likely that fewer forest macrofossils fall directly into the lake. In addition, sedge mats are known to act as filters preventing many macrofossils that might otherwise enter the lake in surface runoff from reaching the lake (Drake and Burrows,1980; McQueen,1969).

Table 4. West shore / east shore ratios for those macrofossils found at five or more sites. The maximum site frequency is sixteen since there were only sixteen nearshore sites (five or fewer meters from shore). The ratios were calculated by dividing a macrofossil's average concentration in the west shore sites by its average concentration in the east shore sites. The macrofossils are listed in order of the statistical significance of their west shore / east shore distributions as calculated by a Mann-Whitney two sample rank test. Where the significance is equal they are listed in order of their west shore / east shore ratios. (*=there were none found in the east shore sites so the ratio could not be calculated)

MACROFOSSIL	RATIO	NEARSHORE SITE FREQUENCY	STATISTICAL SIGNIFICANCE
TSUGA HETEROPHYLLA needles	5.5	14	< 0.002
THUJA PLICATA male cone scales	2.8	16	= 0.01
THUJA PLICATA scale leaves	3.7	16	< 0.02
PHYSOCARPUS CAPITATUS seeds	24.3	6	< 0.1
THUJA PLICATA branchlet units	2.6	16	< 0.1
PSEUDOTSUGA MENZIESII needles	*	6	
ABIES AMABILIS needles	*	4	
NITELLA sp. oospores	*	2	
CRISTATELLA cf. MUC stat.	23.6	6	> 0.1
ISOETES cf. LACUSTRIS megaspores	7.4	6	> 0.1
TSUGA HETEROPHYLLA pollen sacs	5.1	8	> 0.1
ALNUS RUBRA seeds	3.8	4	> 0.1
RUBUS sp. seeds	3.6	15	> 0.1
NAJAS FLEXILIS seeds	3.4	7	> 0.1
THUJA PLICATA seeds	2.4	7	> 0.1
CAREX sp. achenes	2.3	8	> 0.1
DULICHIUM ARUNDINACEUM achenes	2.0	8	> 0.1
PINUS MONTICOLA needles (cm)	1.3	15	> 0.1
TSUGA HETEROPHYLLA seeds	1.0	4	> 0.1
MYRICA GALE bud scales	1.0	12	> 0.1
MENYANTHES TRIFOLIATA seeds	0.8	7	> 0.1
ERICACEAE seeds	0.8	13	> 0.1
NUPHAR LUTEA subsp. POLY. seeds	0.7	5	> 0.1
MYRICA GALE seeds	0.4	7	> 0.1
JUNCUS sp. seeds	0.1	13	> 0.1
RESIDUE VOLUME < 2mm diameter	1.5	-	> 0.1
RESIDUE VOLUME total	1.5	-	> 0.1
RESIDUE VOLUME > 2mm diameter	1.6	-	> 0.1

Still, some macrofossils are more abundant in the east shore sites. These tend to be taxa associated with the sedge mat. However, none of the east shore skewed distributions are statistically significant. This is probably because there is a narrow sedge zone along the west shore, enough to minimize the difference in 'marshiness' between the two sides of the lake.

Comparison With Modern Flora

The frequency of occurrence and average concentration of conifer macrofossils were compared to the relative abundance of the trees in the surrounding forest (Table 5). As might be expected from the abundance of its macrofossils, Thuja plicata is abundant in the forest, accounting for 56 percent of the total basal area within 100 meters of Marion Lake. Similarly, Tsuga heterophylla, which accounts for 35 percent of the basal area, was found at 24 of the 30 sample sites.

Pseudotsuga menziesii needles were found at only 6 sites. The tree is not very common within 100 meters of the lake due to a lack of suitably dry sites but accounts for 7 percent of the basal area within 1000 meters. Pseudotsuga needles may be poorly represented in part due to the difficulty of identifying fragments. Differentiation from Tsuga may depend upon the length to width ratio unless microtome cross-sections are examined (Dunwiddie,1985).

Abies amabilis needles were found at 10 sites despite the fact the tree accounts for only 3 percent of the total basal area. There are, however, several large trees that grow along the inlet stream. Pinus

Table 5. Percent basal area of trees within 100 meters of Marion Lake compared to the site frequency and average concentration of macrofossils in the sediments. The concentration is in numbers per 100 ml of sediment, the frequency out of a total possible 30. Basal areas supplied by Donald McLennan (1981). (*=present but not encountered during sampling)

TAXON	MACROFOSSIL	AVE. [C]	SITE FREQ.	PERCENT B.A.
THUJA PLICATA	scale leaves	304	30	56
	branchlet units	158	29	
	male cone scales	17.6	28	
	seeds	1.07	13	
TSUGA HETEROPHYLLA	needles	6.99	24	34
	seeds	0.515	7	
PSEUDOTSUGA MENZIESII	needles	1.14	6	2.3
ALNUS RUBRA	seeds	2.19	6	3.1
BETULA PAPYRIFERA		-	-	0.1
POPULUS BALSAMIFERA		-	-	3.2
ABIES AMABILIS	needles	0.897	10	2.8
PINUS MONTICOLA	needles (cm)	9.51	25	*

monticola needle fragments were found at 25 of the 30 sample sites despite the fact the tree is rarely found in the forest. It seems that the small fragments of these needles, often only a few mm in length, are well dispersed in the lake.

In September 1982 a qualitative vegetation survey was conducted adjacent to each pair of nearshore sample sites. The presence of all trees and shrubs encountered from the lake margin to and including the edge of the forest was noted. Table 6 compares the presence/absence of macrofossils in the sixteen nearshore sediment samples to the presence/absence of the species in the adjacent vegetation survey. Macrofossils of the conifers are needles or needle fragments (their seeds were encountered only where their needles were present) while, for other taxa, they are seeds or other reproductive structures. The only exception is for the shrub, *Myrica gale*, where fruits occur only where the bud scales are encountered.

Four of the fourteen tree species, all non-coniferous, and ten of the sixteen shrubs are not represented in the macrofossil flora. Species not encountered in the macrofossil flora yet often noted in the vegetation survey may be underrepresented by macrofossil analysis. Included in this category are the trees *Pyrus fusca* and *Acer circinatum*, and the shrubs *Cornus canadensis*, *Ledum groenlandicum*, *Lonicera involucrata*, *Menziesia ferruginea*, *Salix* sp., *Sambucus racemosa* and *Spiraea douglasii*.

Species not often encountered in the vegetation survey yet often represented in the macrofossil flora may be overrepresented by

Table 6. Comparison of the presence/absence of macrofossils in the nearshore samples to near-site vegetation surveys. Numbers left of the solid line indicate, for those sites where the macrofossil was present, the number of times the species was present in and absent from the adjacent vegetation survey. Numbers right of the solid line indicate, for those sites where the macrofossil was absent, the number of times the species was present in and absent from the adjacent vegetation survey. Macrofossils of trees are needles or needle fragments while those of other taxa, with the exception of *Myrica gale* bud scales, are reproductive structures.

	NEARSHORE SITES WHERE MACROFOSSILS PRESENT		NEARSHORE SITES WHERE MACROFOSSILS ABSENT	
	NUMBER OF SITES WHERE TAXON		NUMBER OF SITES WHERE TAXON	
Taxon	Present	Absent	Present	Absent
TREES				
ABIES AMABILIS	0	4	0	12
ACER CIRCINATUM	0	0	6	10
ALNUS RUBRA	0	4	2	10
BETULA PAPYRIFERA	2	2	2	10
PICEA SITCHENSIS	0	2	0	14
PINUS MONTICOLA	2	13	0	1
POPULUS TRICHOCARPA	0	0	4	12
PRUNUS EMARGINATA	0	1	0	15
PYRUS FUSCA	0	0	14	2
PSEUDOTSUGA MENZIESII	2	4	2	8
SORBUS SITCHENSIS	0	0	4	12
TAXUS BREVIFOLIA	0	1	2	13
THUJA PLICATA	14	2	0	0
TSUGA HETEROPHYLLA	12	2	2	0
SHRUBS				
CORNUS CANADENSIS	0	0	6	10
GAULTHERIA SHALLON	7	2	5	2
KALMIA sp.	0	0	4	12
LEDUM GROENLANDICUM	0	0	6	10
LONICERA INVOLUCRATA	0	0	10	6
MENZIESIA FERRUGINEA	0	0	10	6
MYRICA GALE	12	0	4	0
OPLOPANAX HORRIDUM	0	0	2	14
PHYSOCARPUS CAPITATUS	5	1	3	7
RIBES sp.	0	0	2	14
RUBUS PARVIFLORUS	4	7	0	5
RUBUS SPECTABILIS	8	2	4	2
SALIX sp.	0	0	14	2
SAMBUCUS RACEMOSA	0	0	16	0
SPIRAEA DOUGLASII	0	0	16	0
VACCINIUM sp.	9	2	5	0

macrofossil analysis. Species in this category are the tree *Pinus monticola* and possibly the shrub *Rubus parviflorus*. Species encountered often in both the macrofossil flora and the vegetation survey may be good candidates for macrofossil analysis since the macrofossils tend to be found where the plants are observed. Species in this category are the trees, *Thuja plicata* and *Tsuga heterophylla* and the shrub, *Myrica gale*.

THE SAMPLE SITES

In looking at the distributions of the various macrofossils within the lake differences were seen between the nearshore and offshore and between the west shore and east shore sites. The nearshore samples tended to contain a greater variety of macrofossils as well as greater concentrations of any given macrofossil. The west shore sites had greater concentrations of forest-derived macrofossils than the other sites. Thus it appears that knowing the macrofossil composition of a sample may allow one to infer its position within the lake and vice versa. To illustrate these results the macrofossil data were subjected to a principal factor analysis.

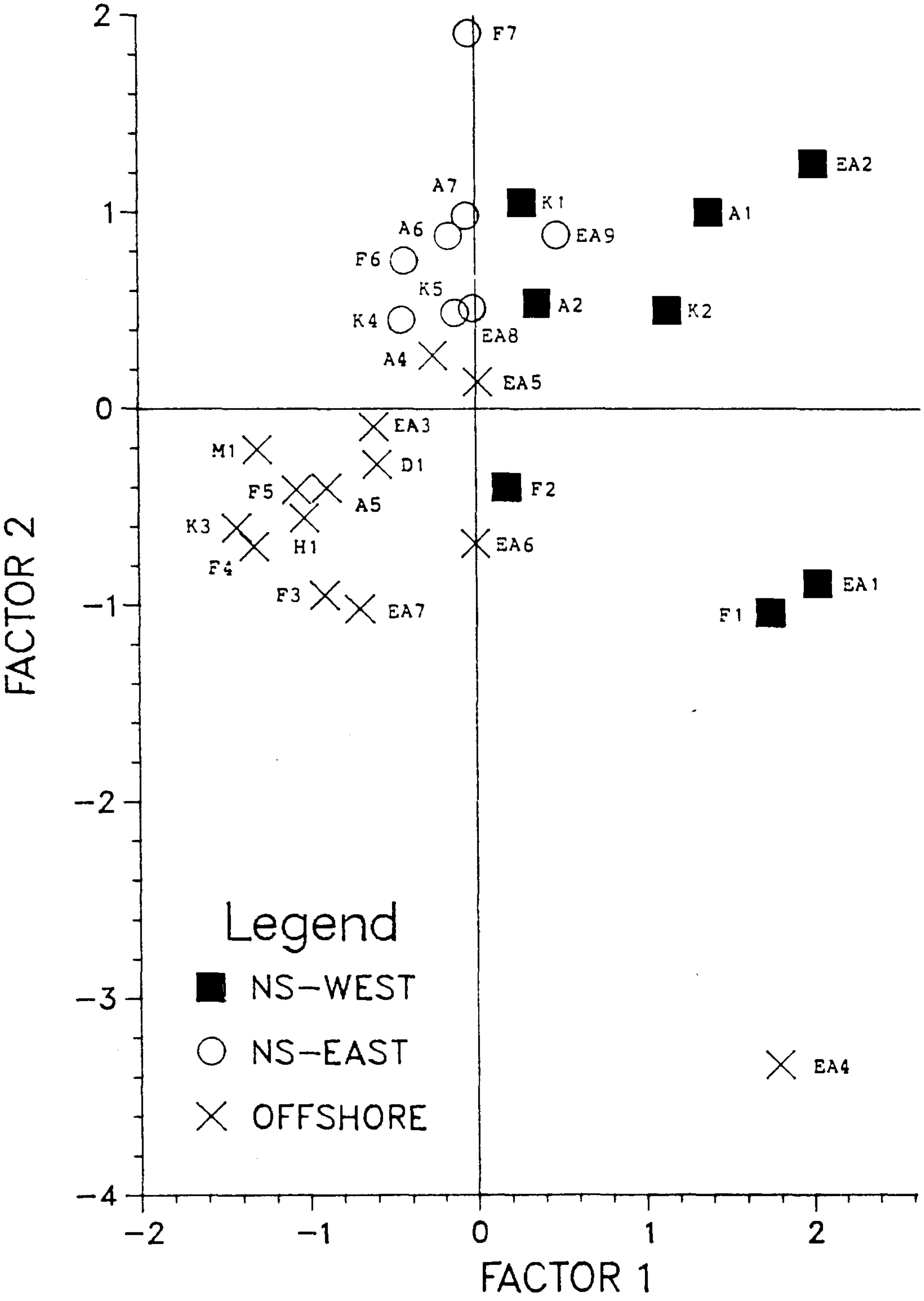
Principal factor analysis is essentially a descriptive technique (Harris,1975). It reduces the complexity of the data by transforming a large number of correlated variables into a smaller set of uncorrelated factors. The percentage of the total variance accounted for by each factor is calculated. Factors that account for a large percentage of the total variance can be investigated further while those that account for little variance can be ignored. For each factor a weighting coefficient, or factor loading, is calculated for each of the samples. These factor loadings can help define the underlying dimension of the factor.

The first two principal factors account for 37.7 percent of the total variance in the data while the remaining 28 factors account for 53.3 percent. By comparing the individual factor scores for each site it is possible to characterize the sites according to their position in the lake. Figure 5 shows a plot of the loadings for factor 2 vs the loadings for factor 1 in each of the 30 sample sites.

The first principal factor, accounting for 25 percent of the variance between the samples, appears to describe the difference between the west shore samples and all other samples in the lake. The west shore sites score above the mean for factor 1 while the east shore sites and the offshore sites, with one exception, score below the mean. It would seem that the west shore / east shore dichotomy is in reality a west shore / any other location dichotomy. Also interesting is the fact that the only other site to have a factor loading above the mean for factor 1 was site EA4. This site is adjacent to the inlet stream where its 'forest character' is likely due to the washing in of macrofossils by Jacob's Creek.

The second principal factor describes the difference between nearshore and offshore sites. All the nearshore east and most of the nearshore west sites have high loadings for factor 2, whereas the factor 2 loadings for most offshore sites are low. The only nearshore sites to have low loadings for factor 2 are F2, F1 and EA1. Sites F1

Figure 5. Factor loadings for factor 2 vs factor 1 for each of the thirty sample sites. The offshore sites are shown by crosses, the east shore sites by open circles and the west shore sites by shaded squares. The west shore sites score high for factor 1. The nearshore sites in general score high for factor 2. The one site that was markedly different from all the other sites was site EA4 (lower right) which was opposite the inlet stream. See Figure 1 for the location of the sample sites. (NS=nearshore)



FACTOR 2
FACTOR 1
2
1
0
−1
−2
−3
−4
−2
−1
0
1
2
F7
EA2
A7
K1
A1
A6
EA9
F6
K5
A2
K2
K4
EA8
A4
EA5
EA3
M1
D1
F5
F2
A5
K3
H1
EA6
F4
EA1
F3
F1
EA7
EA4
Legend
■ NS−WEST
○ NS−EAST
× OFFSHORE

and F2 are adjacent to a small surface runoff inlet which may have reduced their nearshore character. The dry weights of these two samples were markedly higher than for any of the other nearshore samples (see Table 1).

PART C

THE CORE ANALYSIS

CHAPTER I

METHODS

FIELD METHODS

In June 1982 a sediment core was obtained from a location as close as possible to the coring site of Mathewes (1973). A platform was constructed by lashing together two small boats and anchoring them over the coring site in about 6 meters of water. An attempt was made to obtain a complete core using a 7.5 cm diameter Livingstone piston corer (Cushing and Wright, 1965). However, friction prevented sampling with this large diameter corer at depths beyond about 7 meters into the sediment. Consequently, a second core was taken at an adjacent site using a 5 cm diameter corer. A sediment sequence was obtained from the surface to the basal clay at a depth of 8.6 meters. The core segments were brought to the surface a meter at a time and extruded into a plastic trough. Any suspect portions of a segment, such as 'slop' in the top few centimeters, were discarded and the remaining wrapped in cellophane and tinfoil for transport back to the laboratory.

An additional core was obtained from the same site the following year because of a suspicion that the first core may have been contaminated at the 7 and 8 meter drive boundaries. This time the sampling drives were started at the half meter marks; i.e. from 1.5 - 2.5 m, 2.5 - 3.5 m, and so on, such that the boundaries of the previous core segments would fall in the middle of the new segments.

LABORATORY METHODS

In the lab the cores were examined for detritus zones and other obvious variations in texture or colour. In order to obtain as many macrofossils as possible it was decided to analyze the large diameter core down to the level of the Mazama volcanic ash, found at a depth of 5.78 meters into the sediment. This ash fall occurred about 6600 years ago (Powers and Wilcox,1964). Below the level of the ash the small diameter (5 cm) core was used since the large diameter core was unreliable due to sampling problems.

Each section of core representing a drive of one meter was divided into 10 equal segments. Below the level of 8 meters the small diameter core was divided into segments of 5 cm in an attempt to obtain a more detailed look at early postglacial changes. The bulk density, dry weight and loss on ignition of each core segment were determined, using the same method as was used for the surface samples, in order to plot their changes over time. Each core segment was screened and analyzed for macrofossils following the method used for the surface samples.

CHAPTER II

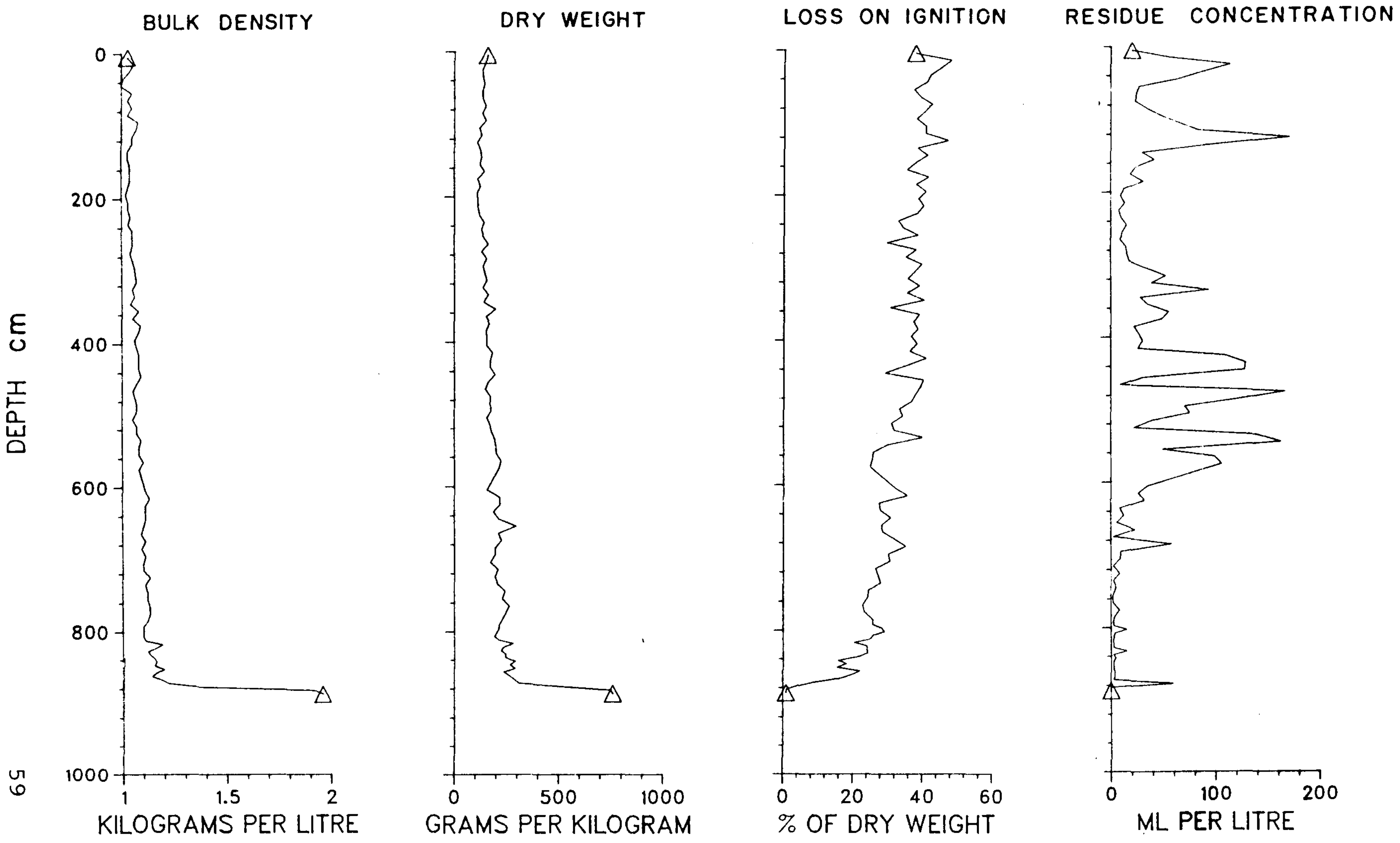
RESULTS AND DISCUSSION

STRATIGRAPHY

As reported by Mathewes (1973) the core consists of olive-brown gyttja which darkened rapidly upon exposure to air. Detritus zones which were found at various intervals correspond well with those found by Mathewes in 1973. The ash from the eruption of Mount Mazama was encountered at a depth of 5.78 meters in the large diameter core and at a depth of 5.90 meters in the small diameter core. At the base of the core the sediment grades rapidly into a blue-grey clay at a depth of 8.6 meters. These values are in close agreement with those of Mathewes who found the Mazama ash at a depth of 6.00 meters and the glacial clay at a depth of 8.65 meters. The two cores were similar enough that dates from the Mathewes core, scaled relative to the markers of the ash and the basal clay, were used for my own core.

Plots of the bulk density, dry weight, loss on ignition, and concentration of residue vs depth in the core are given in Figure 6. The bulk density and dry weight gradually increase with depth as expected. The loss on ignition gradually decreases with depth. The concentration of residue (greater than 250 microns in diameter) is quite variable mainly due to the many detritus zones encountered in the core. The samples taken to determine the bulk density and dry weight were not taken from obvious detritus zones.

Figure 6.: Bulk density, dry weight, loss on ignition and concentration of residue vs depth in the core. Bulk density and dry weight gradually increase with depth. Loss on ignition gradually decreases with depth. The residue concentration was quite variable. High concentrations of residue (greater than 250 microns in diameter) were associated with detritus zones in the core.


BULK DENSITY
DRY WEIGHT
LOSS ON IGNITION
RESIDUE CONCENTRATION
DEPTH cm
0
200
400
600
800
1000
1
1.5
2
KILOGRAMS PER LITRE
0
500
1000
GRAMS PER KILOGRAM
0
20
40
60
% OF DRY WEIGHT
0
100
200
ML PER LITRE

THE INFLUX DIAGRAM

The macrofossil data were plotted using the MICHIGRANA computer program (Futyma and Meachan,1984) for plotting pollen-stratigraphic data. Once the data is placed in a plotfile, the program allows percentage, concentration and influx diagrams to be easily plotted. Some scaling of the macrofossil data and volume units was necessary in order to use the program, since it was designed for the higher concentrations expected in pollen studies.

Figure 7 is an influx diagram showing the frequently encountered taxa. The influx of macrofossils was calculated by multiplying the number of macrofossils per cm^3 by the sedimentation rate in cm per year to yield an influx in numbers per cm^2 per year. The unit used in plotting the diagram is number of macrofossils per 1000 cm^2 per year. This unit was used as a compromise that allowed rare taxa to show up yet prevented excessively high values for abundant taxa. Values used for the sedimentation rate were calculated by Ian Walker, based on radiocarbon dates from the Mathewes (1973) core. A simplified version of Mathewes' (1973) pollen diagram is given as Figure 8. Unless stated otherwise, references to pollen and to the pollen diagram in the following discussion refer to Figure 8.

Western Red Cedar History

The earliest appearance of Thuja plicata as a macrofossil is at a depth of 5.35 meters, or about 6000 years B.P. This contrasts with the Mathewes core where Thuja type pollen (could be other Cupressaceae)

Figure 7. Influx diagram showing the frequently encountered taxa. The influx of macrofossils was calculated by multiplying the number of macrofossils per cm^3 by the sedimentation rate in cm per year to yield an influx in numbers per 1000 cm^2 per year. Ten times auxillary curves highlight the changes in influx. (C-14 dates from Mathewes, 1973)

MARION LAKE – MACROFOSSIL INFLUX

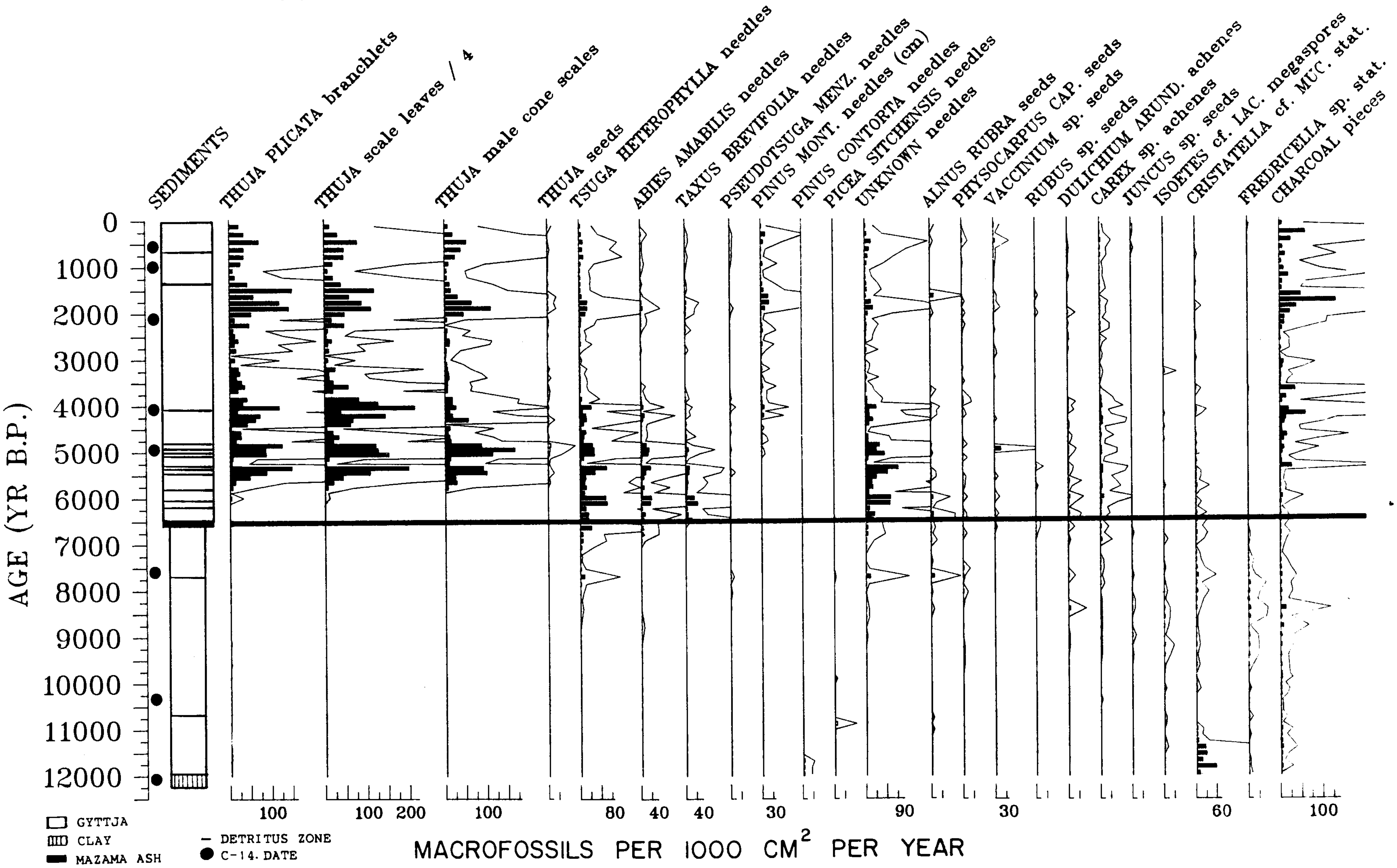
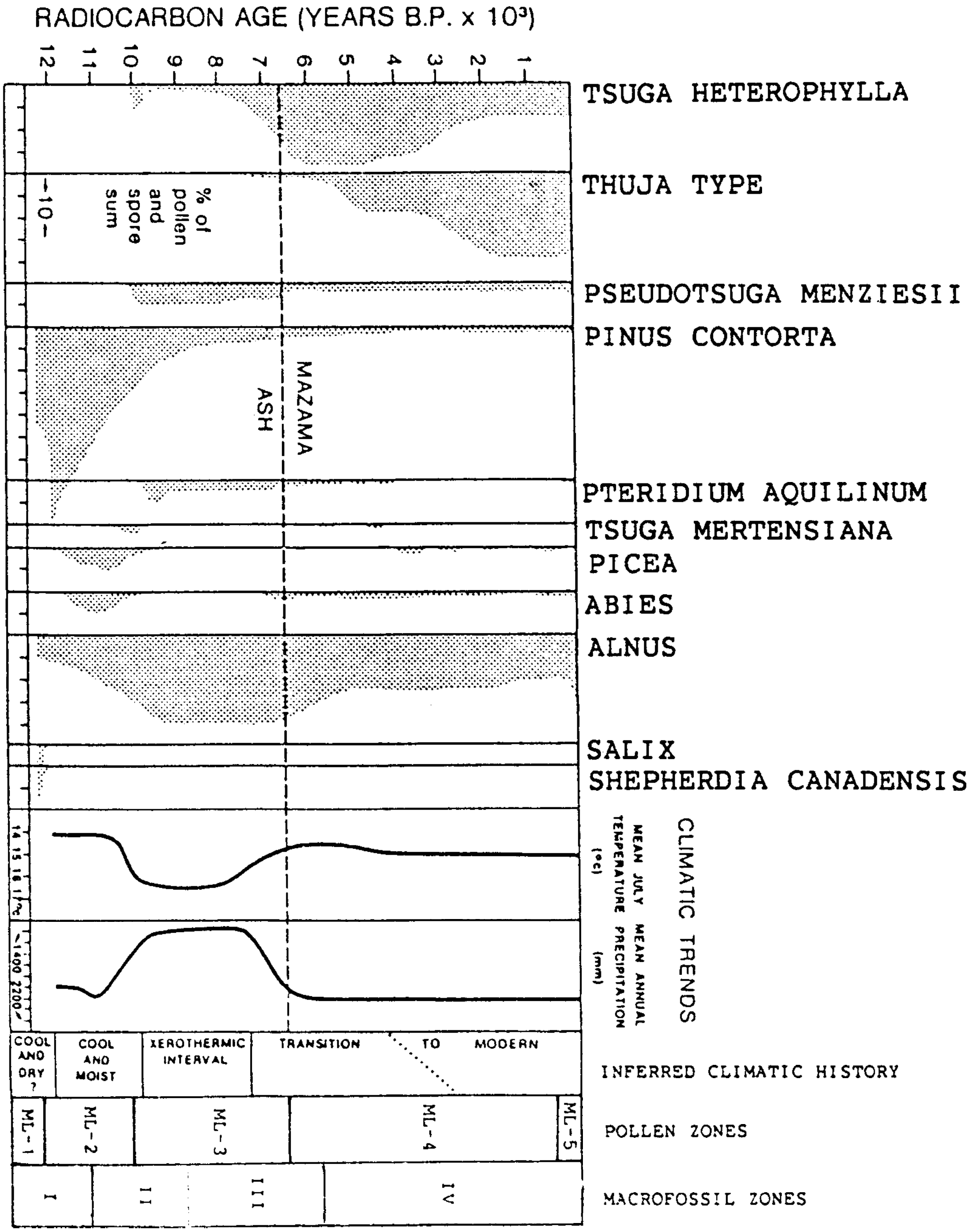


Figure 8. Major trends in Marion Lake pollen diagram (Mathewes,1973) with a histogram of macrofossil zones and temperature and precipitation curves included for comparison.


RADIOCARBON AGE (YEARS B.P. x 10³)
12 11 10 9 8 7 6 5 4 3 2 1
TSUGA HETEROPHYLLA
THUJA TYPE
% of pollen and spore sum
10
PSEUDOTSUGA MENZIESII
PINUS CONTORTA
MAZAMA ASH
PTERIDIUM AQUILINUM
TSUGA MERTENSIANA
PICEA
ABIES
ALNUS
SALIX
SHEPHERDIA CANADENSIS
CLIMATIC TRENDS
MEAN JULY TEMPERATURE (°C)
14 15 16 17 °C
MEAN ANNUAL PRECIPITATION (mm)
~1400 2200~
COOL AND DRY ?
COOL AND MOIST
XEROTHERMIC INTERVAL
TRANSITION TO MODERN
INFERRED CLIMATIC HISTORY
ML-1
ML-2
ML-3
ML-4
ML-5
POLLEN ZONES
I
II
III
IV
MACROFOSSIL ZONES

was found to a depth of 7.35 meters or about 7800 years B.P. In addition, Mathewes found sporadic occurrences of *Thuja* type pollen *and* macrofossils at a depth of 8 meters or about 10,000 years B.P. Similar sporadic ocurrences of *Thuja* macrofossils at the top of the seventh and eighth core segments in my first core prompted recoring the site with the start of each drive offset 50 cm from those of the previous core. Examination of the residue from the core segments surrounding the seven and eight meter marks in this second core revealed no *Thuja* macrofossils. *Thuja* macrofossils found at the seven and eight meter marks in my first core were present due to contamination at the core boundaries. Since the *Thuja* macrofossils reported by Mathewes were also at the start of a drive it is likely that they too were the result of contamination.

Thuja type pollen found as far back as 7800 years B.P. is probably of some other taxa such as *Chamaecyparis* or *Juniperus*. The record of *Thuja* macrofossils in the form of scale leaves, branchlet units, male cone scales and seeds is overwhelming, from their initial appearance in the core to the present. It is highly unlikely that *Thuja* could have been in the drainage basin from 7800 B.P. without some occurrence of macrofossils in the core prior to 6000 B.P. For the 500 year period prior to the appearance of *Thuja* the influxes of *Tsuga*, *Abies* and *Taxus* needles are at their maximum levels. Considering the ubiquity of the *Thuja* macrofossils, especially the vegetative ones which were found in *all* surface samples, it seems more likely that *Thuja* entered the basin not long before the macrofossils first appear in the core about 6000 B.P. It is at about this time that *Thuja* pollen begins to consistently exceed five percent of total.

Western Yew History

Taxus brevifolia needles first appear just prior to the Mazama ash at 6600 years B.P. Its history is often not documented by pollen studies perhaps due to the difficulty in distinguishing it from Cupressaceae. Taxus is presently of minor importance in the Pacific Northwest and most authors assume a minor role in the past. The macrofossil evidence suggests that Taxus may have been a more important component of the forest around Marion Lake prior to the arrival and expansion of Thuja plicata. For a period of 1100 years, from about 6500 to 5400 B.P., the influx of Taxus needles is as high as that of Abies amabilis and is nearly half that of Tsuga heterophylla. The input of Taxus needles averages 35 per core segment over 11 consecutive segments. In the modern surface sediment study Taxus needles were found at only three sites at an average concentration equivalent to 3 per core segment. It is not until after the appearance of Thuja that Taxus needles decline. From 5000 B.P. to the present Taxus needles are only rarely encountered in the core. It is possible that Thuja displaced Taxus as both species prefer moist sites (Krajina et al.,1982). Such an interpretation points out the need for a Taxus category on Pacific Northwest pollen diagrams.

Pine History

The only evidence of Pinus contorta found in the core was needles found in one sample just above, and two samples just below the clay/gyttja interface at the base of the core. No identifiable macrofossils were found more than 10 cm into the basal clay. The Pinus contorta needles occur at a point where its pollen is nearly 100 percent of the total. Pinus contorta has been noted in many other Pacific Northwest studies as one of the first immigrants on recently deglaciated terrain (Mathewes,1985). The species seems to have played an important role in the U.B.C. research forest only in the initial period following deglaciation. Its consistent presence in the pollen record since then is most likely due to regional transport or from stunted individuals on nearby rock outcrops (McLennan and Mathewes, 1985).

Pinus monticola needle fragments are first found at a depth of 4.45 meters or about 5100 years B.P. They increase to the present day, although only isolated individuals are found in the forest around Marion Lake today (McLennan,1981). The consistent occurrence of needle fragments in the core from 5100 years B.P. is probably a result of their overrepresentation as was seen in the surface sample study. Although Pinus monticola pollen is found below 8 meters (Mathewes,1973), it is not found in excess of 1 percent of the total below a depth of 4.3 meters.

Balsam Fir History

The first occurrence of Abies needles is at a depth of 7.55 meters or about 9000 years B.P. However, they are not frequently encountered below 6.35 meters or about 7000 years B.P. The pollen record suggests that prior to 10,000 years B.P. Abies was at least as common as it is today. This is not reflected in the macrofossil record even though there is a good correspondence above 7.55 meters between the occurrence of Abies needles and the presence of pollen. The needles found are probably all of Abies amabilis. The earlier pollen, on the other hand, is possibly that of Abies lasiocarpa from higher altitudes. Needles of Abies lasiocarpa may not have been incorporated in the sediments as a result of the long distance to the lake. A similar situation was seen with Pseudotsuga menziesii in the surface sample study where, although the tree is present on the hillsides today, the needles are only rarely encountered in the surface samples.

Western Hemlock History

The first occurrence of Tsuga heterophylla needles is at a depth of 7.35 meters or about 8600 years B.P. Tsuga pollen was found by Mathewes at the clay-gyttja interface about 12,000 years B.P. However, it does not consistently exceed 10 percent of the total pollen until its needles are found in abundance about 8000 B.P. There is a peak exceeding 20 percent of the total pollen around 10,000 years B.P. in the Mathewes diagram, and there are similar peaks in other Pacific Northwest diagrams, although the macrofossils are not encountered at this time in the Marion Lake core. However, all macrofossils are uncommon during the early postglacial. It may be Tsuga was present but its needles were not making their way to the coring site due to differences in the drainage characteristics of the basin (see Changing Drainage Patterns).

Douglas Fir History

Needles of Pseudotsuga menziesii are first found at a depth of 7.05 meters or about 8000 years B.P. Pollen of Pseudotsuga, up to 10 percent of the total, is found from 10,000 B.P. However, needles of Pseudotsuga were rarely encountered in the surface sediment samples even though the tree is consistently present, 7 percent of total basal area, on the hillsides around the lake. Since influxes of all macrofossils were low prior to 7000 B.P., it is likely that Pseudotsuga was present, probably away from the lakeshore, from about 10,000 B.P. without needles being transported to the coring site. The low influx of Pseudotsuga needles may indicate a lack of suitably dry sites near the lake as its needles are more frequently encountered in other Pacific Northwest studies (Cwynar, 1985).

Bryozoan Statoblasts

The significance of the peak of Cristatella cf. mucedo statoblasts (Plate III-8,b) at the base of the core is uncertain. However, this species rarely occurs in polluted water or where oxygen content falls below 30 percent (Reynolds,1976). Perhaps the cool clear waters of the early postglacial were conducive to its growth and the subsequent reduction in numbers an indication of eutrophication of the lake. The peak of Fredricella sp. statoblasts (Plate III-8,a), found between 9500 and 7500 B.P., is in the middle of the postglacial xerothermic interval (Mathewes and Heusser,1981) suggesting a possible relationship with warmer summer temperatures.

Changing Drainage Patterns

Several lines of evidence indicate that much of the organic matter in Marion Lake is allochthonous, brought into the lake via inlet streams and surface runoff. Odum (1978) reports that allochthonous input of particulate organic carbon in Marion Lake is in excess of 70 grams/m^2/yr and that more than 80% of this input is fluvial. The detritus zones in the core contained sand leading Mathewes (1973) to suggest that they were deposited during periods of high fluvial input. Most of the macrofossils in the core are found in these detritus zones. There is a thick detritus layer on the bottom of the lake near the inlet stream. Mclennan (1981) found that stream erosion accounted for about 67% of the total pollen input into Marion Lake sediment. Changes that alter the flow rate and patterns of erosion in the Marion Lake catchment are therefore likely to be reflected in the abundance of macrofossils deposited.

There is a drop in influx of all taxa between 3 meters and 1.5 meters in the core. This portion of the core spans some 1700 years from 3700 to 2000 years B.P. An additional period of reduced influx is seen circa 1300 B.P. It is most likely that during these periods there was some major change in the drainage pattern of the basin. A layer of peat along Jacob's Creek about 300 meters upstream from from the lake attests to the past presence of a significant depositional basin. A photograph of the upper layers of this peat bed can be seen can be seen in Plate IV. It is apparent from the photograph that late peat accumulation was intermittent, with alluvial lenses of sandy or silty sediment interspersed. The changes in macrofossil input to Marion Lake

Plate IV. Photograph showing dark layer of peat, buried by alluvium, along Jacob's Creek upstream from Marion Lake. A radiocarbon date from the base of the peat coincides with the start of a period of reduced influx of macrofossils circa 3700 years B.P. A date from the top of the peat (0.3-0.4 on rod) coincides with a second period of reduced influx circa 1300 years B.P.

PLATE IV

likely represent the filtering effect of this ancient sediment trap.

The base of the peat bed was dated at 3900 ± 160 years B.P. (SFU-305). This coincides almost exactly with the sudden and marked decrease in macrofossil influx into the lake circa 3700 B.P. Further, a sample of peat from the top of the bed was dated at 1330 ± 60 years B.P. (Beta-14267). This coincides well with the second decrease in macrofossil influx seen circa 1300 B.P. It seems that the input of macrofossils to Marion Lake has been reduced by this settling basin upstream from the lake. The origin of the basin is unknown, although there presently is, and likely was, beaver activity along Jacob's Creek. The outlet to the lake is an ideal place for a dam and evidence of past activity there remains. A rise in water level by a few meters would be sufficient to cover much of the floodplain above the present lake.

Prior to 7000 B.P. the influx of all macrofossils is very low. These low early influxes are possibly evidence of the postglacial xerothermic interval (Mathewes and Heusser, 1981). There is no indication of a depositional basin upstream from the present lake during this time. As most of the macrofossils in the core are found in the detritus zones that appear to result from periods of high runoff and erosion in the watershed, an extended period of reduced average annual precipitation would likely result in a period of reduced macrofossil influx, especially if the reduction occurred during peak periods.

The Charcoal Record

It is interesting to note that during the 1700 year period of reduced macrofossil influx, 3700 to 2000 years B.P., the influx of charcoal was also reduced. Further, the reduced macrofossil influx circa 1300 B.P. and the low values prior to 7000 B.P. are also reflected in a reduced charcoal influx. This suggests the charcoal pieces counted in this study also enter the lake during periods of high runoff and erosion in the watershed. Such an interpretation has interesting implications for the use of charcoal data from this lake. If most of the charcoal is fluvially derived, a marked increase of charcoal could be an indication of increased precipitation and erosion of catchment soils rather than of fire activity at the time of deposition.

When one compares the record of charcoal in Marion Lake to a precipitation curve for the area (Mathewes and Heusser,1981), the increased charcoal due to increased precipitation hypothesis seems to hold up. A simplification of this curve is appended to the pollen diagram in Figure 8. One of the most significant aspects of the curve is the suggestion of a marked increase in annual precipitation in the mid Holocene. To quote R.W. Mathewes (1985,p415),

> "Although the nature of early to mid Holocene climate is controversial, there is widespread agreement among geologists and paleobotanists that the climate of the late Holocene became colder and wetter".

There is a marked increase in influx of charcoal in the core following this accepted increase in average annual precipitation.

The association of increased charcoal influx with a wetter climate can be explained in that only charcoal pieces retained on a 250 micron sieve were counted. Pieces of charcoal as large as this are probably not carried long distances by wind. Burzynski (1984) found that pieces of this size and larger fall within 1 kilometer of the burn site even when wind speeds are as high as 20 kilometers per hour. It seems more likely this charcoal would enter the lake via erosion from the soil during periods of high runoff.

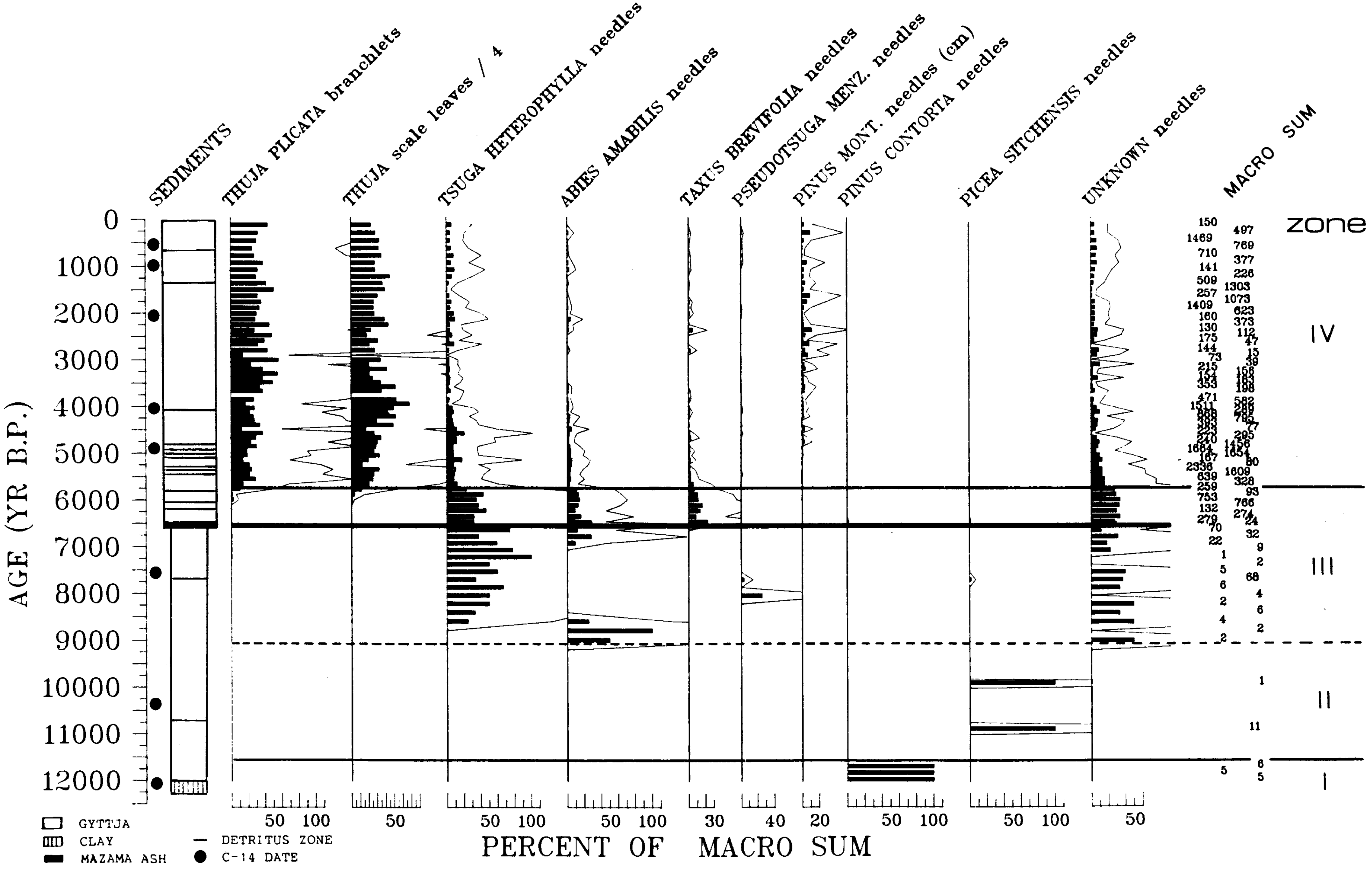
THE PERCENTAGE DIAGRAM

Figure 9 is a percentage diagram including only 'needles' of conifers. Seeds were too uncommon to plot. Although *Thuja* branchlets and scale leaves are not strictly equivalent to needles, they were used in the the calculation of the percentages. The number of scale leaves was divided by 4, since it takes four scale leaves to make one branchlet unit. The total length in cm of *Pinus monticola* needle fragments was used since whole needles were rarely encountered.

One obvious change in the percentage diagram is the marked increase in the needle sum at about the level of the Mazama ash some 6600 years B.P. This increase precedes the appearance of *Thuja plicata* macrofossils in the core by about 600 years and coincides well with the increase in mean annual precipitation predicted upon the basis of pollen transfer functions (Mathewes and Heusser,1981). It is not surprising that an increase in needle sum should coincide with an increase in mean annual precipitation given the abundant evidence to

Figure 9. Percentage diagram for conifer needles. Zones were determined using the pollen zonation program developed by Gordon and Birks (1972). (C-14 dates from Mathewes,1973)

MARION LAKE – MACROFOSSIL PERCENTAGE



suggest macrofossils are washed into the lake during periods of high runoff.

Surprisingly, this increase in needle sum is not reflected in the pollen sum. McLennan (1981) found as much as 67% of the pollen deposited in Marion Lake could be attributed to fluvial input. One would think that as more macrofossils are washing in more pollen should be washing in. However, it is likely that, as the waters of Jacob's Creek slow upon entering the lake, the larger and heavier macrofossils settle out while the smaller and lighter pollen grains are carried on. Pollen trapping in the outlet (McLennan,1981) shows large losses occur by flushing into the outlet stream.

From its first occurrence as a macrofossil in the core about 6000 years B.P., Thuja plicata quickly dominates the needle sum. The initial reduction in the percentages of other needles coinciding with the arrival of Thuja are a result of the new arrival and do not represent a real reduction in numbers. Subsequent reductions in the percentages of Abies, Taxus and Tsuga represent reductions in the numbers of these needles in the core. The only needles to increase in percentage after the arrival of Thuja were fragments of Pinus monticola needles which did not appear in the core until about 5100 years B.P.

Macrofossil Zonation

The data for the macrofossil percentage diagram were zoned using the 'Zonation' program developed by Gordon and Birks (1972). This program was designed to numerically split pollen diagrams into zones using measures of the total variability between the levels. The three most significant discontinuities in the data were at spectra 73, 50 and 91 using both the SPLITLSQ (least sum of squares) and the SPLITINF (information content) methods of zonation. Boundary lines have been drawn on the diagram just below each of these spectra.

The following is a comparison (Figures 8 & 9) of the macrofossil zones (I to IV) to the pollen zones (ML-1 to ML-5) described by Mathewes (1973).

Pollen ZONE ML-1 is within the glacial clay. Peaks of *Shepherdia canadensis*, *Salix sp.* and *Pinus contorta* pollen suggest cool continental conditions. This zone corresponds with ZONE I on the macrofossil diagram. The only identifiable macrofossils here were a few needles of *Pinus contorta* found at and within 10 cm of the gyttja/clay interface.

Pollen ZONE ML-2 represents a decline in *Pinus contorta* pollen and an increase in *Abies*, *Tsuga mertensiana* and *Picea*. ZONE II at the base of the macrofossil diagram corresponds to pollen zone ML-2. *Pinus contorta* needles disappear and needles of *Picea sitchensis* are found sporadically. Needles of *Tsuga* and *Abies* are not found in this zone. However, the percentage of *Tsuga* pollen is low, and the *Abies* pollen may very well be that of *Abies lasiocarpa* from higher altitudes. A dotted line has been drawn between macrofossil zones II and III since there were few macrofossils in this portion of the core.

Pollen ZONE ML-3 represents a period after the decline in *Pinus* pollen but before the arrival of *Thuja*. There is a reduction in pollen of *Picea* and *Abies* but the latter increases again towards the end of the zone. There is an increase in *Tsuga heterophylla* and *Pseudotsuga menziesii*. *Taxus* pollen is not recorded. This zone corresponds with macrofossil ZONE III. *Abies amabilis* needles are found and increase along with *Taxus brevifolia* towards the end of the zone. *Picea* needles disappear except for a single occurrence in the middle of the zone. *Tsuga heterophylla* needles are found as are needles of *Pseudotsuga menziesii*, even though the latter appear to be poorly represented in the macrofossil flora on the basis of the surface sample study. This zone overlaps with the postglacial xerothermic interval (Mathewes and Heusser,1981).

Pollen ZONE ML-4 represents the probable local arrival and subsequent increase of *Thuja plicata*. This zone corresponds with macrofossil ZONE IV, although the pollen diagram once again establishes the start of the zone prior to the date established by the macrofossil diagram. *Thuja* pollen likely arrived before the tree, although prior to 6600 years B.P. the *Thuja* type pollen is possibly of other Cupressaceae. The overwhelming abundance of *Thuja* macrofossils from 6000 years B.P. to the present and the total absence prior to 6000 years B.P. suggest that *Thuja* was not present near the lake prior to this date.

Pollen ZONE ML-5 is not found on the macrofossil diagram. This zone represents an increase in the occurrence of successional species mostly due to historical forest disturbance. Since successional species were poorly represented in the surface sample study, the absence of this zone on the macrofossil diagram is not surprising.

PART D

SUMMARY AND CONCLUSIONS

SUMMARY

The Traditional Uses of Macrofossils

The traditional uses of plant macrofossil data to supplement pollen data are well established (Watts,1980). The validities of two main uses, to establish the local presence of taxa whose pollen travels long distances on the wind, and to establish the specific identity of taxa whose pollen is not easily differentiated, have been confirmed by this study.

According to the pollen data, Thuja plicata was potentially present but rare in the Marion Lake drainage basin as early as 7800 years B.P. The macrofossil data suggest it is unlikely Thuja was in the drainage basin much prior to 6000 years B.P. Thuja macrofossils predominate from their first appearance in the core at 6000 B.P. For 500 years prior to this date the influxes of other taxa are at their maximums with no evidence of Thuja and Thuja macrofossils were most ubiquitous in the surface sediment study. The earlier report of macrofossils at 10,000 years B.P. by Mathewes (1973) is likely the result of contamination at a core segment boundary.

Taxus brevifolia was not recorded in the pollen diagram. The macrofossil diagram establishes Taxus as an important local species for a period of about 1100 years from 6500 to 5400 years B.P. During this period the influxes of Taxus, Abies amabilis and Tsuga heterophylla needles are higher than at any other time. Twenty percent are Taxus, twenty percent are Abies and the remaining are Tsuga.

The Surface Sediment Study

Whether macrofossils can be used to produce meaningful vegetation reconstructions, analagous to those produced using pollen data, depends upon whether they are sufficiently mixed and dispersed to represent the composition of the local vegetation (Birks and Birks,1980). A particular site may be biased in favour of some taxa over others, but this bias should be predictable from the location of the site. This study has shown that, in Marion Lake, there is a good dispersal of coniferous macrofossils and that some of the biases in the dispersal can be predicted from the location of the site.

There are significantly more macrofossils from forest species in the west shore sites than in the east shore sites. Conversely, there were more sedge marsh macrofossils in the east shore sites than in the west shore sites. These differences result from differences in the topography and vegetation composition between the shores. The west shore is steeper without the bordering sedge marsh than can be found along the east shore.

Offshore sites are macrofossil poor relative to the nearshore sites but macrofossils of conifers are consistently present. The occurrence of upland taxa in offshore sampling sites appears to be the result of fluvial input, mainly by Jacob's Creek. Lenses of detritus, resulting from periods of high runoff and erosion in the watershed, were the main source of macrofossils in the core. A change in the drainage pattern can drastically alter the input of macrofossils, as seen in the reduced influx of all macrofossils between 3700 and 2000 years B.P. Evidence indicates that a past depositional basin above the present lake may have been responsible for this reduction.

Vegetative macrofossils, mainly of the forest conifers, were found at significantly greater average concentrations ($p<0.05$) and at significantly more sites ($p<0.025$) than were reproductive macrofossils. For most other taxa, reproductive structures were more abundant than vegetative ones. Branchlet units, scale leaves and staminate cone scales of Thuja plicata are ubiquitous. It would be difficult to take a surface sediment sample of 100 ml or more from Marion Lake without obtaining evidence of Thuja.

Although Pseudotsuga menziesii is consistently present, accounting for 7 percent of the total basal area within 1000 meters of the lake (McLennan, 1981), its needles were rarely encountered in the surface samples. Pinus monticola needle fragments, on the other hand, were found at most sites despite the fact that it accounts for less than 1 percent of the total basal area.

The Macrofossil Diagrams

The establishment of local presence using macrofossils is more conclusive but there is generally good agreement between the macrofossil and pollen dates. Pinus contorta needles are present at the clay/gyttja boundary 12,000 years B.P. at a time when pine pollen is at its maximum. Pinus monticola needles are present from 5100 B.P. The pollen is present from 10,000 B.P. but rarely exceeds 1 percent of the total until the needles appear. Abies amabilis needles appear at 9000 B.P. but do not become common until 7000 B.P. Abies pollen is at its maximum between 12,000 and 10,000 B.P. and becomes common again at about 7000 B.P. The early pollen is likely that of *Abies lasiocarpa* from higher altitudes. *Tsuga heterophylla* needles first occur at 8600 B.P. becoming common by 7000 B.P. *Tsuga* pollen peaks briefly at 10,000 B.P. but does not again exceed 10 percent of the total until the needles become common. *Picea sitchensis* needles are found between 10,000 and 11,000 years B.P. at a time when pollen is at its maximum. *Pseudotsuga menziesii* needles first occur at 8000 B.P. while pollen is common from 10,000 B.P. The needles are never common in the core probably indicating the tree occupied drier sites away from the lake.

Paleoecological interpretations based upon the macrofossil diagrams are similar to those based upon the pollen diagram. There is a good correspondence between the zones on the macrofossil percentage diagram and those on the pollen diagram although the start of each pollen zone predates its macrofossils analogue. This is to be expected given the long distance transport of pollen relative to macrofossils. The only pollen zone that did not have a macrofossil analogue was ZONE ML-5, representing a historical increase in successional species which were poorly represented as macrofossils in the surface sediment study.

The increase in influx of macrofossils of all kinds just prior to 6600 years B.P. corresponds with a period in which it is generally accepted that the climate in the area became cooler and wetter (Mathewes,1985). In a lake where fluvial input of macrofossils is important, it is not surprising that a long term increase in macrofossil influx for most types should coincide with a period of increased average annual precipitation. Conversely, the low influx of macrofossils prior to 7000 B.P. may be evidence of a postglacial xerothermic interval (Mathewes and Heusser,1981). The influx of charcoal parallels the influx of macrofossils suggesting that pieces of charcoal greater than 250 microns in diameter enter the lake primarily during periods of high runoff and erosion in the watershed rather than as a result of fire activity at the time of deposition.

Together, the percentage and influx diagrams provide a more accurate reflection of the forest composition than either could alone. During the period of reduced influx, from 3700 to 2000 years B.P., the percentage diagram shows the relative abundance of needles in the core remained essentially unchanged. When the percentages of all other taxa drop drastically with the rapid expansion of Thuja, the influx diagram shows their needles are as abundant as ever in the core.

CONCLUSIONS

The surface sediment study provided insights which were valuable in the interpretation of the macrofossil diagrams. The demonstrated ubiquity of its macrofossils was important in establishing the first local presence of Thuja plicata at 6000 years B.P. The evidence that upland macrofossils are present in the offshore sites as a result of fluvial input, largely by the main inlet stream, allows an increase in the total influx of macrofossils in the core to be interpreted as an indication of increased runoff and erosion in the drainage basin. In a lake with a major inlet stream, a prolonged increase in the total influx of macrofossils may be an indication of an increase in the average annual precipitation or of an increase during peak periods. The log of the average concentration vs site frequency plot showed those macrofossils found in high concentrations were found at most sites, suggesting the dispersion necessary for a good reconstruction based upon macrofossils.

There is a good representation of most forest conifers as macrofossils in the core. A history based solely upon plant macrofossil analysis from this site would probably be as valid as one based solely upon pollen analysis, provided the macrofossil influx was continuously high. The history from 7000 to 12,000 B.P. is less certain due to low influxes, although the pollen evidence is not contradicted by the macrofossil evidence during this time. A percentage diagram complements an influx diagram when total influxes are variable. There is no doubt that a combined macrofossil / pollen study is superior to a study based upon pollen or macrofossils alone, especially where the influx of macrofossils is high. An offshore site under the influence of an inlet stream may be a good place to collect upland macrofossils but is apt to show a variable total influx.

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