POLLEN-CLIMATE TRANSFER FUNCTIONS

FOR THE

WESTERN INTERIOR OF CANADA

By

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ABSTRACT

The objective of this project was to construct pollen-climate transfer functions for the Western Interior of Canada and to apply these to dated fossil pollen records to obtain estimates of past climates.

Climate curves from the calibration functions were constructed for summer precipitation and temperature, fall precipitation and temperature, winter temperature, and spring temprature.

The palaeotemperature estimates suggest winter and fall temperatures were warmer during the mid-Holocene whereas the summer and spring temperatures suggest there was no significant difference in temperature between this time and the present. results are not in accordance with the Milankovitch estimates of Holocene insolation variation or the conclusions of previous palaeoclimatic studies in the region.

The palaeoprecipitation estimates constructed indicate decreased precipitation during the mid-Holocene. Increased aridity in the mid-Holocene is consistent with both the Milankovitch theory and the results of previous palaeoclimatic reconstructions from the study area. However, it is not clear if the high aridity reflects decreased precipitation or increased evapotranspiration.

The theoretical and practical limitations of the pollen-climate transfer function approach to this approach to the estimation of paleoclimates are discussed.

ACKNOWLEDGEMENTS

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INTRODUCTION

The Milankovitch orbital geometry theory of global climatic change asserts that during the present glacial period the maximum solar radiation in the northern hemisphere occurred at 10,000 BP (Berger,1981). At this time the mid to high latitudes received seven percent more insolation in summer than at present along with seven percent less insolation in the winter (Kutzbach and Otto-Bliesner, 1982). Thus, summer temperatures were higher and there was a greater seasonality than at present (Berger, 1981; Kutzbach and Otto-Bliesner,1982). These conditions continued until 6000 BP when changes in orbital parameters reduced insolation resulting in a cooling trend and decreased seasonality. Around 3000 BP conditions are thought to have reached those approximating today's.

Research is now being undertaken to determine if the terrestrial geologic record supports the Milankovitch theory. In Western Canada the acquistion of proxy climatic data useful in testing the Milankovitch hypothesis has focussed on the northern and southern edges of the Boreal forest. These ecotonal regions are particularly sensitve to climatic variation (Bryson and Wendland,1967; Ritchie and Hare, 1971; MacDonald and Ritchie, in press). At the northern treeline Ritchie et al. (1983) concluded from pollen and plant macro-fossil evidence from the MacKenzie delta that the period of maximum summer warmth occurred around 10,000 BP. In addition ^{14}C dated basal sediments of thermokarst basins along the adjacent coastal lowlands provide evidence of a period of maximum melting of ground ice between 9000 and 10000 BP (McCulloch and Hopkins, 1966).

At the southern boreal forest boundary Lichti-Federovitch (1970), used pollen evidence to draw tentative conclusions about an early to mid-Holocene warm period in central Alberta which appears to support the Milankovitch theory. The pollen evidence suggests warm conditions between 8500 and 6000 BP and a deterioration of climate reaching modern conditions around 3000 BP. Pollen analysis from the northern precints of glacial Lake Agassiz also provide evidence of an early to mid-Holocene thermal maximum which support the Milankovitch theory (Ritchie, 1983). Vance et al. (1983) used three lakes in central Alberta to analyse fossil pollen data as well as charcoal remains and pyrite spherule concentrations. They determined that between 7400 BP and 5000 BP the regional vegetation developed a more open structure than that which presently exists and was subject to frequent fires. They suggest this was a response to warm dry climatic conditions during the mid-Holocene. Their records indicate the establishment of a cooler, moister climate at 4000 BP.

White and Mathewes (1982) examined fossil pollen from a pond in the Peace River district of British Columbia. They determined the formation of the pond occurred around

7230 BP and was a result of a transition from arid conditions in the mid-Holocene to moister conditions in the late Holocene.

Last and Schweyen, (1985) reconstructed the post hysithermal history of Waldsea lake in Saskatchewan and deduced that the lake was a shallow hypersaline lake around 4000 BP and from there cooler moister conditions ensued resulting in increased lake levels. Recently, Matthews et al., (in press) summarized the Holocene paleoecological history of the western plains. Radio carbon dated sediments from lakes and bogs in central Alberta provide a detailed history of lake formation and water level fluctuations which indicate that a prolonged severe drought must have characterized the mid-Holocene.

Mathews et al., (in press) also compared pollen records from Lofty Lake (Lichti-Federovitch, 1970) and Moore Lake. Moore Lake which is situated along the southern boreal forest ecotone in east central Alberta demonstrates frequency changes in pollen, charcoal and pyrites between 5800 BP and 9200 BP which indicate that increasing drought and aridity allowed expanding grassland to displace the southern limit of the boreal forest. They suggested that the maintenance of the grassland was aided by increased frequency of fire in the drought stressed forest. A reversal of this trend is thought to have occurred just before 5800 BP and the grassland was replaced by spruce forest.

With the exception of a tentative qualitative temperature reconstruction by Ritchie (1983), the above studies provide only inferential evidence of temperature and moisture during the postulated Milankovitch early to mid-Holocene insolation maximum. However, the pollen-climate transfer function approach provides the potential to obtain quantitative estimates of climatic conditions during the Holocene.

Pollen climate transfer functions are basically multiple regression equations based on the relationship between modern pollen surface samples and modern climate parameters. Fossil pollen frequencies are then used as the predictor variables to provide estimates of temperature, precipitation and other parameters (Howe and Webb,1983).

In this thesis I will construct pollen-climate transfer functions from a network of modern pollen samples from Western Canada (MacDonald and Ritchie, in press) (Figure 1.) I will then apply the resulting transfer functions to a fossil pollen record from central Alberta (Lichtie-Federovich,1970) to provide quantitative temperature and precipitation estimates for the Holocene. The results of the palaeoclimatic reconstruction will be compared to the theoretical expectations generated by the Milankovitch model and the results of previous studies in the region. Both the practical and theoretical limitations of this approach will be discussed.

METHODOLOGY

TRANSFER FUNCTION CONSTRUCTION

Howe and Webb (1983, p. 17) state: "When properly calibrated, Holocene pollen data provide an important source of quantitative information about Holocene climates." Multiple linear regression of modern climate and pollen data allows for the development of statistical calibration functions which transfer percentages of certain pollen types into quantitative estimates of climatic variables (Howe and Webb, 1983). These functions are then applied to fossil pollen and paleoclimatic estimates are derived. Howe and Webb (1983) provide a regression relationship between climate and pollen which can be expressed as the paleoecological equation $C=P\cdot\beta+\epsilon$ where:

C is an m-vector $(c_1, \ldots\ldots c_m)'$ of observations of a climatic variable;

P is an m-by-(n+1) (where m>n) matrix with element $p(i,1)=1.0$ and with $p(i,j)$ the percentage of pollen type j in sample i for n pollen types indexed $j=2,3,\ldots.n+1$.

β is an (n+1)-vector of unknown parameters and ϵ is an m-vector of errors.

Howe and Webb, (1983) outline a series of steps to be followed when constructing a calibration function. This procedure was followed in constructing transfer functions for the Western Interior of Canada and is described below.

Choice of Climate Parameters to be estimated

In order to determine whether warmer and moister conditions than today existed in the mid Holocene estimates of precipitation and temperature are required. It has been demonstrated that pollen rain in the Western Interior of Canada reflects the distribution of major vegetation zones (MacDonald and Ritchie, in press). Therefore, any relationship between climate and vegetation should be reflected as a relationship between pollen rain and climate. However, since itisunknown exactly how the vegetation responds to temperature it was felt neccessary to obtain correlation coefficients for the various taxa and climate parameters, and to attempt to construct calibration functions for the following climate variables:

Temperature variables

1. January average temperature
2. July average temperature
3. Summer average temperature (June, July, August)
4. Winter average temperature (December, January, February)
5. Six month summer average temperature (May, June, July, August, September, October)
6. Six month winter average temperature
7. Standard deviation of July average temperature
8. Standard deviation of January average temperature fall average temperature (September, October, November)
9. Spring average temperature (March, April, May)

Precipitation variables

1. January average precipitation
2. July average precipitation
3. Summer average precipitation
4. Winter average precipitation
5. Spring average precipitation
6. Fall average precipitation
7. Six month summer average precipitation
8. Six month summer average precipitation
9. January average precipitation standard deviation
10. July average precipitation standard deviation

By estimating these parameters a number of possible relationships between temperature regime and vegetation distribtution can be assessed. The use of standard deviations provides an indication of plant response to the amount of variation from the mean and if calibration of these is possible it can be determined climatic variability has changed over the Holocene.

The precipitation parameters were chosen basically for the same reasons as were the different temperature parameters. Using these parameters it is possible to estimate the precipitation regime through the mid Holocene. Frost free days and growing degree days were also chosen for estimation since these are connected to temperature changes and it was possible that plants may have shown a greater direct response to these cumulative parameters.

The Geographic Region Where Modern Pollen and Climate Data Are Collected

The major pollen types and the variations in their percentages within the set of modern data should approximately match those of the fossil data and if possible the modern samples should slso be from sediments similar to those in which fossil pollen accumulated (Howe and Webb, 1983) The site from which the fossil pollen was obtained is Lofty Lake which is located in the boreal forest at 54°44′ N and 112°29′ W (Figure 1). The Lofty Lake profile (Figure 3) is divided into five zones (Lichti-Federovich, 1970). The first zone extending from 11500 to 10000 BP and reflects a *Populus*-shrub pioneer vegetation on the recently deglaciated terrain. Zone 2 extends from approximately 10000 to 9000 BP and represents a landscape covered by *Picea* forests. The third zone extending from 9000 to 7500 reflects a continuous deciduous forest dominated by *Betula* and *Populus*. The fourth zone extending from 7500 to 3500 represents parkland vegetation. The final zone extending from 3500 BP to the present reflects the modern Boreal forest vegetation. There are no modern pollen samples similar to the pollen samples older than 7500 BP at Lofty Lake (MacDonald and Ritchie, in press) so once calibration functions are constructed we can only have confidence in estimates between 7500 BP and the present.

A set of 105 sites was the initial choice for the

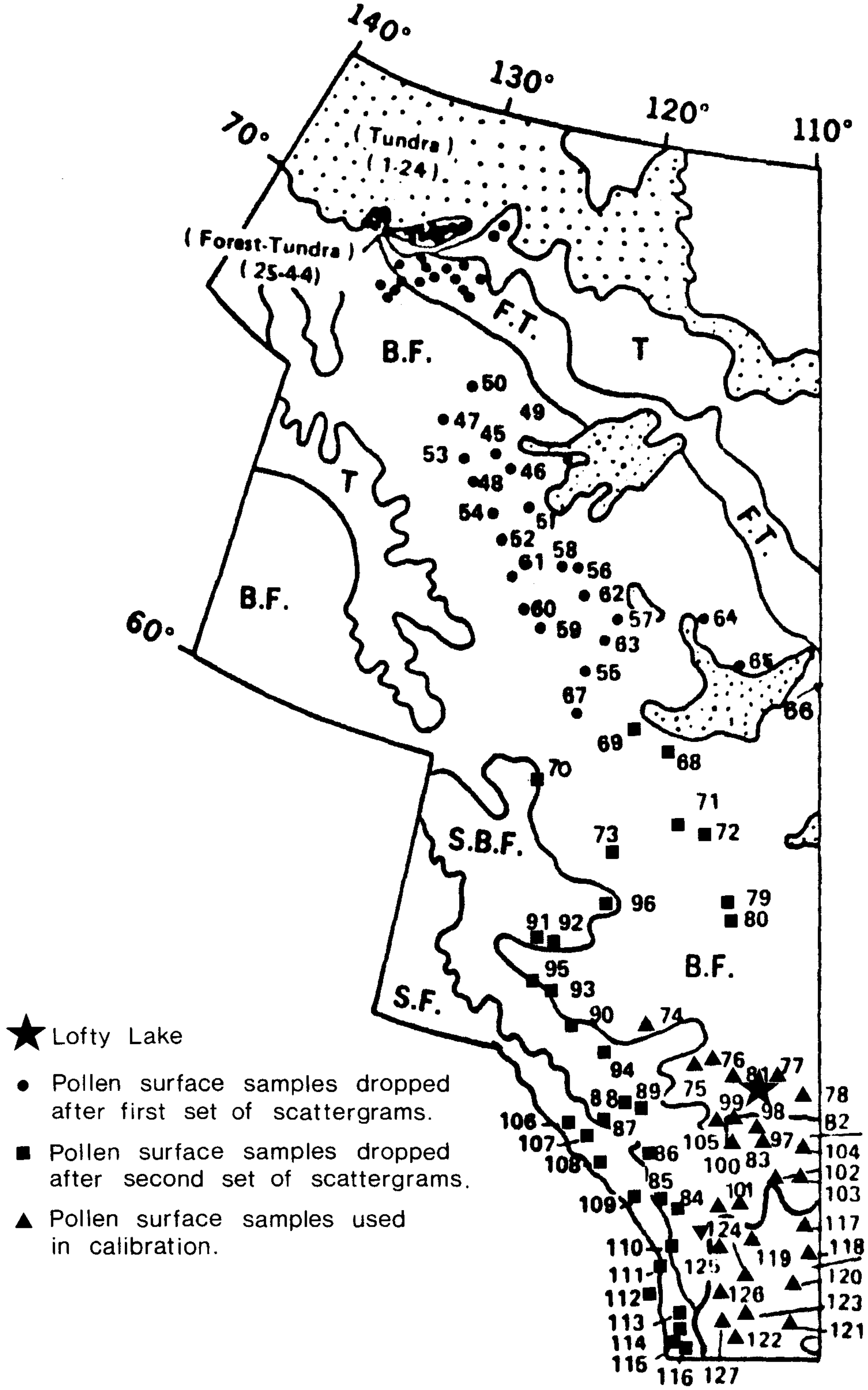

Figure1 . The location of the modern pollen surface sample sites and the major vegetation zones of the study area: (T) Tundra, (F-T) Forest-Tundra, (B.F.) Boreal Forest, (S.B.F.) Subalpine-Boreal Transition Forest, (S.F.) Subalpine Forest, (Pk) Parkland, (G) Grassland (after Rowe, 1972).

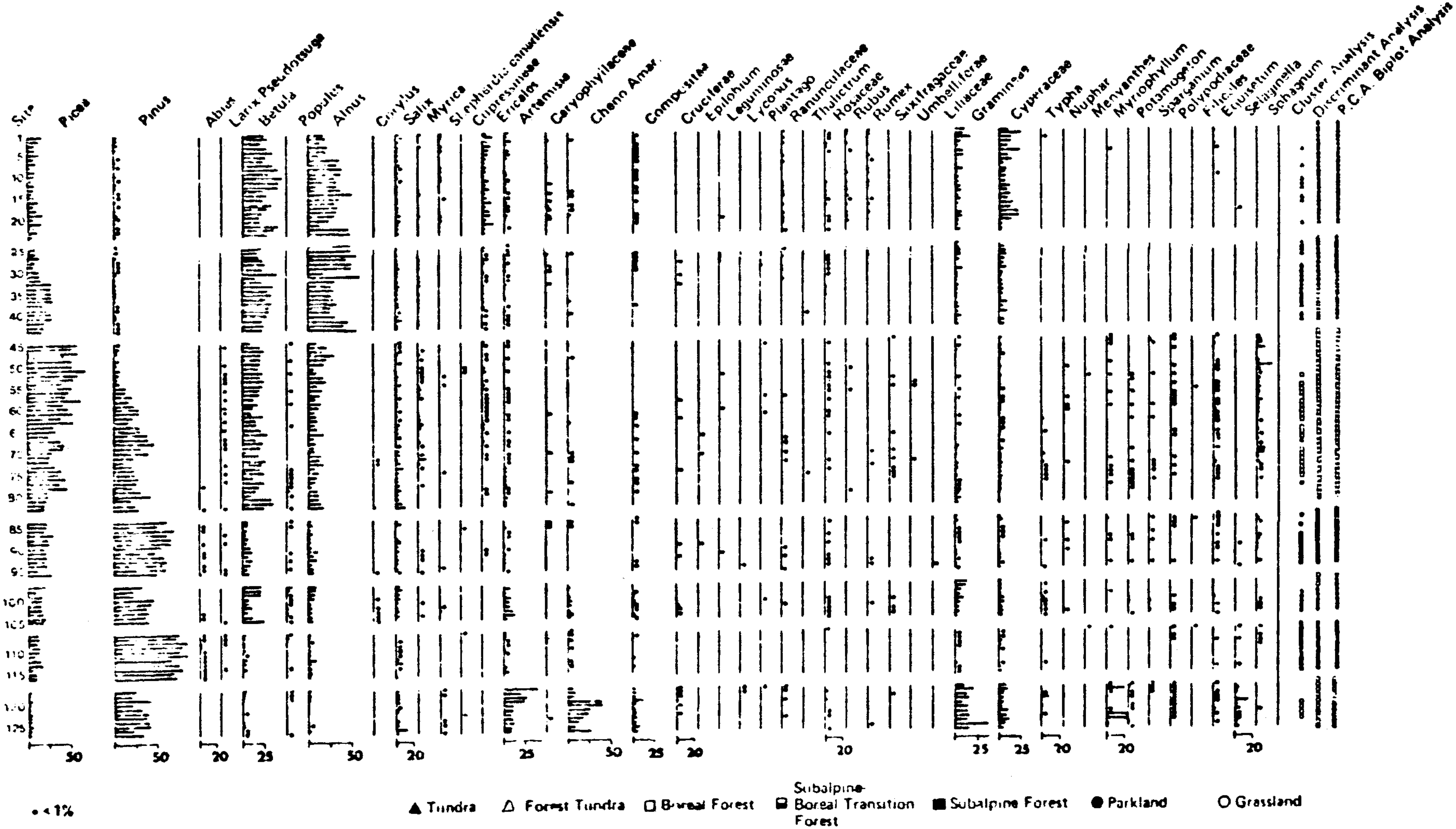

Figure 2 . The modern pollen spectra of the study area and the results of the numerical classification of the samples.(After MacDonald and Ritchie, in press)

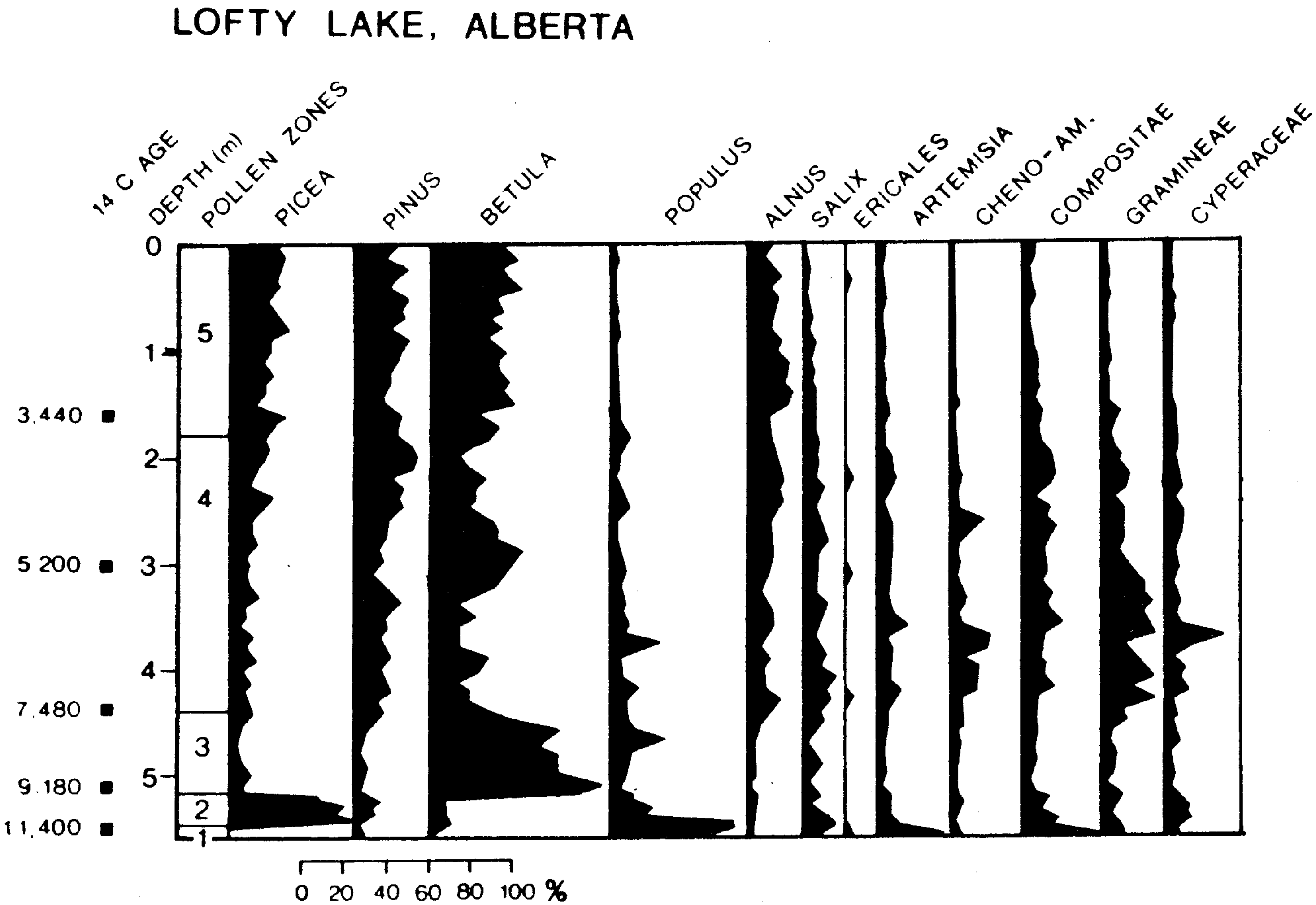

Figure 3. Fossil pollen diagram of the fossil pollen site. (After Lichti-Federovich, 1970)

calibration data set. These 105 sites are from lake cores over a wide geographic region ranging in latitude 69°57′N to 49°03′N (Figure 1). The sites encompass tundra, forest tundra, boreal forest, subalpine forest, subalpine boreal transition forest, parkland, and grassland vegetation zones. The inidividual sites were taken from various studies performed in Alberta and the Northwest Territories (MacDonald and Ritchie, in press).

Climate data were taken from records obtained from meteorologic stations usually within 100 km of the surface sample site. Where sites were not within 100 kilometers of a meteorologic station, the climate data were obtained by interpolation between the two nearest meteorologic stations. If the site was not equidistant between the two stations the values from the two stations were weighted accordingly. Thus each pollen site had a corresponding set of climate parameters. The climate data were taken from the meteorologic stations in the Canada Climate Normals (1982,a,b,c,d).

Choice of the initial pollen sum

The pollen data from the modern sites and the fossil pollen site are in percentage form since conversion to percentages serves to standardize the data within and between lakes as well as provide data sets with geographic trends that can be calibrated against climate. 47 pollen types were included in the preliminary pollen sum. Pollen taxa chosen for inclusion in the calibration pollen sum were chosen on the basis of the following criteria;

1) the mean pollen value is at least 1 percent;
2) the mean is less than 1 percent but the maximum is greater than 5 percent.

The taxa satisfying these criteria were Picea, Pinus, Betula, Populus, Alnus, Salix, Artemisia, Cheno Am (Chenopodiaceae and Amerantheae), Compositae, Gramineeae, Ericales, and Cyperaceae.

Scatter diagrams to determine monotonic relationsips

Once the initial pollen sum was chosen it was neccessary to determine if relationships between modern climatic parameters and pollen samples were linear and monotonic. Monotonic linear relationships are required to build multiple regression equations i.e pollen frequencies should increase or decrease monotonically with the climatic variable. To determine if the relationships were monotonic and linear, scatter diagrams of the chosen pollen taxa and the various climatic parameters were constructed.

The scattergrams are plots of individual pollen taxa versus a climate parameter. Scattergrams allow for easy identification of anomalous of outlier observations (Howe and Webb, 1983) as well as revealing whether or not a given relationship is monotonic and linear. Outlier observations may result from inherent variability and these should be incorporated into the model as well as measurement error and execution error due to biased sampling or including observations which are un representative of the population of interest. Outliers due to measurement error should be corrected if possible or eliminated (Howe and Webb, 1983) as should be those which are unrepresentative of the population of interest. The modern pollen surface data and the climate data were put into a data matrix and SPSS (Statistical Package for the Social Sciences was employed to construct the scattergrams.

The initial scattergrams plotted for all the sites revealed definite non-monotonic relationships. Inspection of the scattergrams indicated a reasonable point at which "cut off" the more northerly points. For example the Betula- January temperature scattergram (Appendix 6) revealed an increase in pollen amount with increasing temperature to 60° N at which point the pollen amounts began to decline with increasing temperatures. This is reasonable since the northern limit of the boreal forest is contolled by lower temperatures and the southern limit is controlled by decreasing temperatures (Bryson, 1966) In order to obtain the desired monotonic relationship, the sample size was decreased to 63 sites (Figure 1) by dropping sites from the northern boreal forest and the tundra, and the scattergrams were replotted. With this run, relationships became monotonic but outliers and anomalous sites still existed. These sites lay in either the subalpine boreal forest transition zone or in the subalpine forest (Figure 1). These sites were eliminated since their anomalous values were likely due to elevational climate controls on vegetation rather than latitudinal control. Four individual sites not in the above vegetation regions were also eliminated. The anomalous sites were likely sites with unusual characteristics which Howe and Webb (1983) recommend be eliminated from the model. The remaining 24 sites were then used to produce scattergrams a final time.

The SPSS package supplies correlation coefficients with each scattergram. Since once monotonic relationships were established, the relationships were not neccessarily linear, it was neccessary to transform some of the pollen taxa. This was done using SPSS. The r values provided by SPSS indicate the improvement of r with transformation of the relationship. The improvement of the Betula-January temperature curve is shown in Appendix 6. Appendices 2 and 3 show the final r values obtained for the various climate variables and pollen taxa.

REGRESSION

On the basis of the r values, candidate taxa for the calibration functions were chosen. Taxa were chosen for inclusion in the calibration function if their correlation coefficients with the various climate parameters were greater than .50 or less than -.50 and significant at the .05 alpha level. Some of the climate parameters could not be calibrated since fewer than five taxa showed a significant relationship with that variable (Appendices 2 and 3). The one exception to this was the spring temperature since it was thought that a significant relationship might still be achieved on the likelihood of strong vegetational response to spring temperature. The climate parameters which were retained for estimation were spring average temperature, fall average temperature, summer average temperature, winter average temperature, six month summer average temperature, six month winter average temperature, summer average precipitation, fall average precipitation, and six month summer average precipitation

There are several techniques available for constructing a regression equation when there are two or more explanitory or predictor variables. The method chosen for the construction of the calibration functions was the all possible subsets. The equations are provided in the form,

$$y = b + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots + \beta_n x_n$$

where y is the estimated variable, x_1-x_n are the predictor variables, b is the intercept and $\beta_1 - \beta_n$ are the coefficients.

Once the candidate pollen taxa (predictor variable) were chosen associated with each climate variable the equations were produced using the all possible subsets method on BMDP (Biomedical computer programs P- series package). This produces a multiple regression equation for each climatic variable and associated plant taxa. This is done by evaluating equations associated with each subset of independant variables from the total set of independent variables (Howe and Webb, 1983).

Testing the statistical assumptions

Analysis of the residuals is the main method used to determine the appropriateness of the statistical assumptions of normality, homogeneity of variance, and independance of regression residuals (Howe and Webb, 1983). An initial check of the assumptions is provided by examining a scatter diagram in which standardized residuals are plotted against estimated values of the dependant variable (Appendix 4). When no statistical assumptions are violated, the points are randomly scattered on the horizontal band with points becoming less dense furthest away from the x axis (Howe and Webb, 1983). This was the case with all the regression equations obtained for the climate variables so by this criterion the statistical assumptions have been met.

The normal distribution of the errors is important for multiple regression and can be determined by a normal probability plot which ideally demonstrates a y=x relationship if the residuals are normally distributed. The errors from all of the regression equations follow this y=x relationship (Appendix 5).

Homogeneity of variance is indicated by the standardized residuals having a constant variance and can be evaluated by inspection of the scattergram of the standardized residuals against estimated values. If this assumption is not violated the scatter will appear random and there will be no change of variance with estimated value. The regression equations constructed meet this criteria (Appendix 4).

Confidence Interval Estimation

A 95% confidence interval was determined for the regression equations using the standard error of the estimate multiplied by 1.96 which is the t-value for the 95% confidence interval. The standard error of the estimate is given by: $SEE = \tilde{\sum}\sqrt{\frac{(Y - Y')^2}{N}}$

Where Y are the actual values and Y' are the predicted values and N is the sample size. Thus the true value of the climate variable estimated from the regression is about 95% certain to lie within 1.96 standard errors on either side of the estimated value.

Paleoclimate estimation

The equations for the various climate parameters were applied to the Lofty Lake fossil pollen site, using BMDP also which predicts the climate values usng the precalibrated regression equations.

Once the paleoclimate estimates were produced by BMDP the values were plotted against age to obtain paleoclimate curves. The age of each fossil increment was determined by calculating sedimentation rates between each carbon dated interval and interpolating to determine the age of the increment within the stratigraphy.

RESULTS

Temperature

The transfer function equations for estimating the various paleoclimatic parameters at Lofty Lake are presented in table 1. As was discussed in the methodology, we cannot have confidence in estimates beyond 7500 BP the results from these parts of the estimated curves are not presented.

The six month summer average temperature curve (Figure 7) (based on October, September, August, July, June, May) demonstrates little change over the last 12000 years. The greatest variation occurs from between 6000 BP and the present when temperatures appear to drop from 12.2°C to 11.5 °C. The error bars for this curve indicate that none of the temperature variations are significant.

The three month summer average temperature curve (June ,July and August), (Figure 6) also indicates little change over the last 12000 years. There is no change evident until 4000 BP at which point the curve begins to oscillate between 14.75°C and 15.75°C.

The 6 month winter average temperature curve (Figure 5) increases up to a peak of - 6.4°C at 6000BP and then decreases to today's level of -8.8°C. These changes are statistically significant over the curve and the magnitude of the change from 6000BP to present is -2.4°C.

TABLE 1: CALIBRATION FUNCTIONS FOR THE CLIMATE VARIABLES (significant at alpha=.05)

SPRING AVERAGE TEMPERATURE (R^2=.85)

$$y=1.394-.006\sqrt{PICEA}+.037\sqrt{BETULA}+.219\sqrt{ALNUS}+.012\sqrt{CHENOAM}$$

FALL AVERAGE TEMPERATURE (R^2=.90)

$$y=1.393-.083\sqrt{PICEA}-.015\sqrt{BETULA}+.112\sqrt{ALNUS}+.654\sqrt{CHENOAM}-.162\sqrt{COMPOSITAE}-.049\sqrt{GRAMINEAE}$$

LONG SUMMER AVERAGE PRECIPITATION (R^2=.86)

$$y=47.570+.464\sqrt{BETULA}-.310\sqrt{ALNUS}-1.588\sqrt{CHENOAM}+1.641\sqrt{PICEA}+.808\sqrt{COMPOSITAE}-.733\sqrt{ARTEMISIA}+.344\sqrt{GRAMINEAE}$$

SUMMER AVERAGE PRECIPITATION (R^2=.86)

$$y=75.66+.181\sqrt{BETULA}-.708\sqrt{ALNUS}-4.568\sqrt{CHENOAM}+1.168\sqrt{PICEA}+.841\sqrt{COMPOSITAE}-1.00\sqrt{ARTEMISIA}$$

LONG SUMMER AVERAGE TEMPERATURE (R^2=.83)

$$y=11.793-.001\sqrt{BETULA}-.127\sqrt{ALNUS}+.070\sqrt{CHENOAM}+.009\sqrt{PICEA}+.036\sqrt{COMPOSITAE}$$

LONG WINTER AVERAGE TEMPERATURE (R^2=.85)

$$y=-9.802-.053\sqrt{BETULA}+.321\sqrt{ALNUS}+.979\sqrt{CHENOAM}-.060\sqrt{PICEA}-.488\sqrt{COMPOSITAE}+.288\sqrt{GRAMINEAE}$$

SUMMER AVERAGE TEMPERATURE (R^2=.76)

$$y=16.403-.045\sqrt{PICEA}-.034\sqrt{BETULA}-.021\sqrt{ALNUS}+.044\sqrt{CHENOAM}+.122\sqrt{COMPOSITAE}-.454\sqrt{SALIX}$$

WINTER AVERAGE TEMPERATURE (R^2=.82)

$$y=-14.244-.181\sqrt{PICEA}-.158\sqrt{BETULA}+.296\sqrt{ALNUS}+.991\sqrt{CHENOAM}+.777\sqrt{COMPOSITAE}-.454\sqrt{SALIX}$$

FALL AVERAGE PRECIPITATION (R^2= .86)

$$y=1.86+.973\sqrt{BETULA}-.505\sqrt{ALNUS}+1.168\sqrt{CHENOAM}+3.698\sqrt{PICEA}+.814\sqrt{COMPOSITAE}+.376\sqrt{ARTEMISIA}+1.62\sqrt{GRAMINEAE}$$

The three month (Dec, January, February) winter average temperature curve (Figure 4) was similar to the six month one however the amplitude of the change was greater with the temperature decrease from 6000 BP to present of the order of 3°C decreasing from -11°C to -14°C. From 1180 to 8000 BP the temperature decreases from -11.5 to 15 C. Temperature increases over the period 7500 to 6000 BP from -15°C to -11°C, a change of 4°C. From 5000 BP to present a decrease is observed from -14°C to -11°C, a 3°C change. This difference in temperature is also statistically significant.

The temperature changes of the fall average temperature curve (Figure 8) are also statistically significant and the same general trend is evident as with the winter temperatures. Temperature increases from 7500 to 4.3 C at 6000 BP and decrease of 4°C to 3°C is recognized from 6000 BP to present. The magnitude of the change from 6000 BP to present is 1°C.

The spring temperature curve (Figure 9) does not show significant temperature changes.

Precipitation

The six month summer average precipitation curve (Figure 10) increases significantly from 11400 BP to 9000 BP from 441 mm to 58 mm. A decrease is shown from 7500 BP to 6000 BP to 49 mm, a total change of 7 mm. From this point, precipitation increases significantly to the present.

The magnitude of the change is 8 ºC.

The summer average precipitation (Figure 11) follows the same pattern as the long summer average precipitation but the magnitude of the variations are greater. From 7500 BP precipitation decreases 13mm down to 65mm st 6000 BP. Beyond this, precipitation increases significantly to its modern day levels at about 75 mm.

Fall average precipitation (Figure 12) exhibits more change over the Holocene than the two summer precipitation curves and the values are significant. From 7500 BP to present, precipitation increases 10 mm from 20mm to 30mm.

Summary

From the individual climate curves, the following reconstruction for the mid-Holocene is indicated.

Temperature increases from 7500 BP reaching a peak around 5800 to 6000 BP. From here, temperature decreases to present day levels. The fall and winter curves are the most significant. Due to the insignificance of the summer average temperature curves (both six month and three month) it cannot be determined whether or not there was greater seaonality during the mid-Holocene. Since the summer curves indicate no change, any differences between summer and winter temperatures during the Holocene indicated by the curves is only a reflection of the winter temperature change.

The precipitation curves are all significant and display a decrease to about 6000 BP which corresponds to the increase in temperature at this time. Precipitation then increased to the present day levels.

The fall and winter temperature curves and the precipitation curves indicate higher temperatures and lower precipitation during the mid-Holocene.

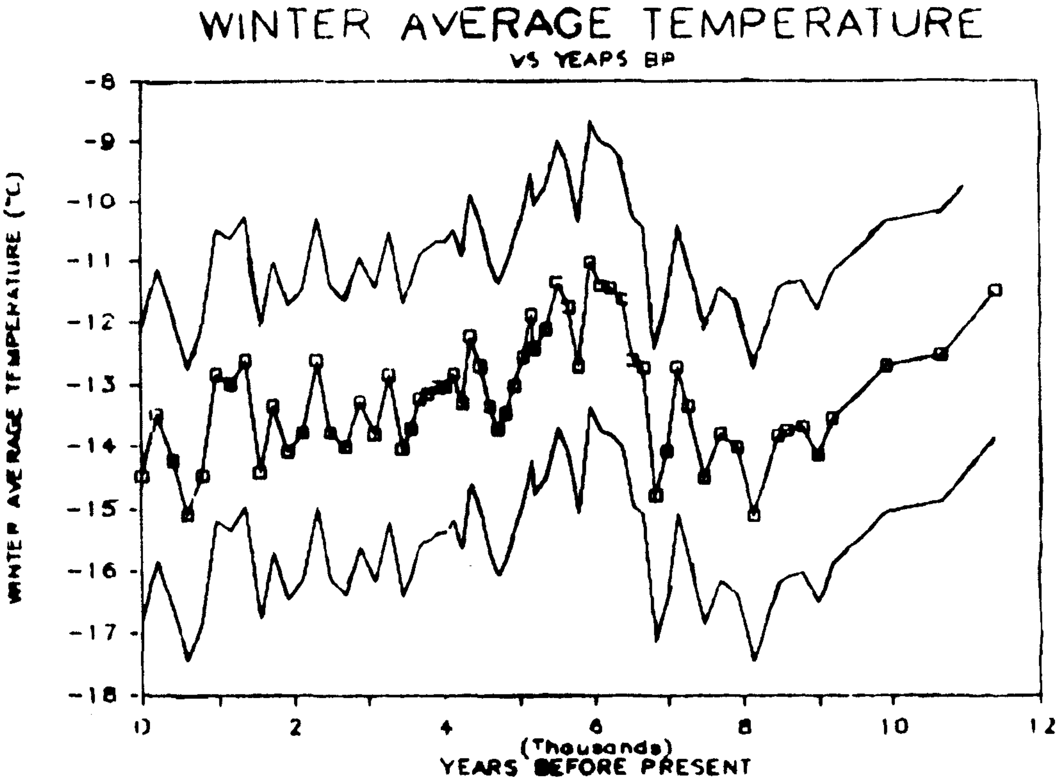

Figure 4. Winter average temperature curve

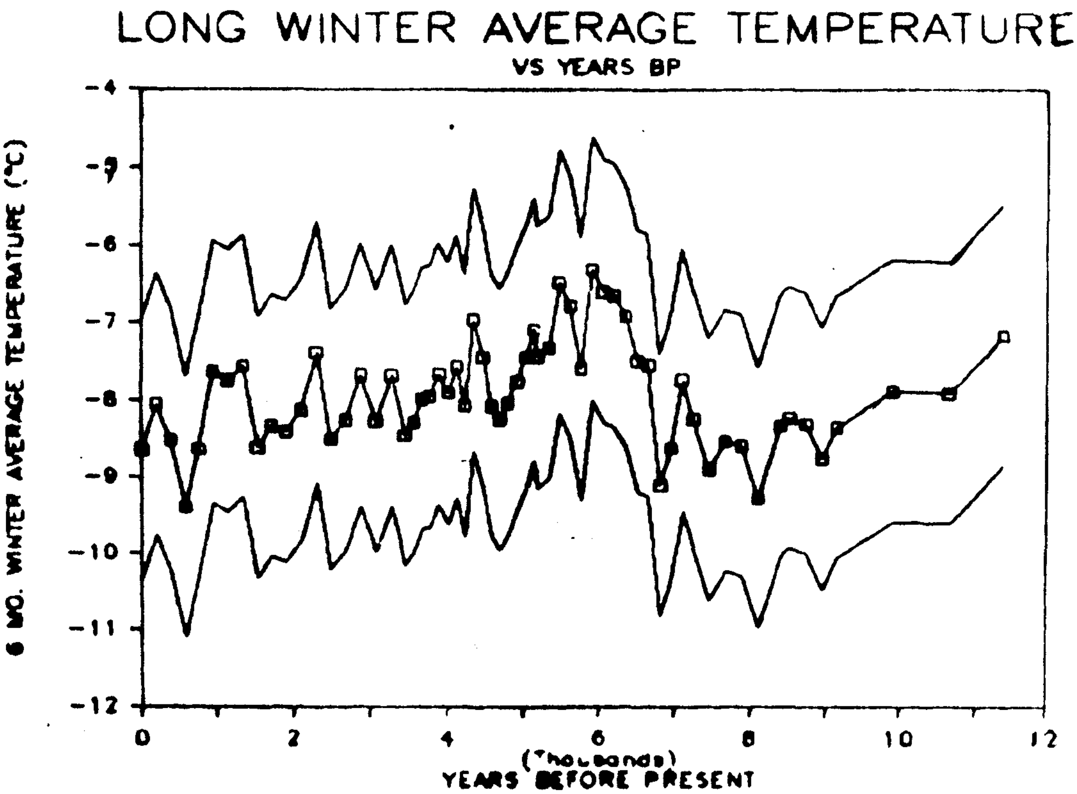

Figure 5. Long winter average temperature curve

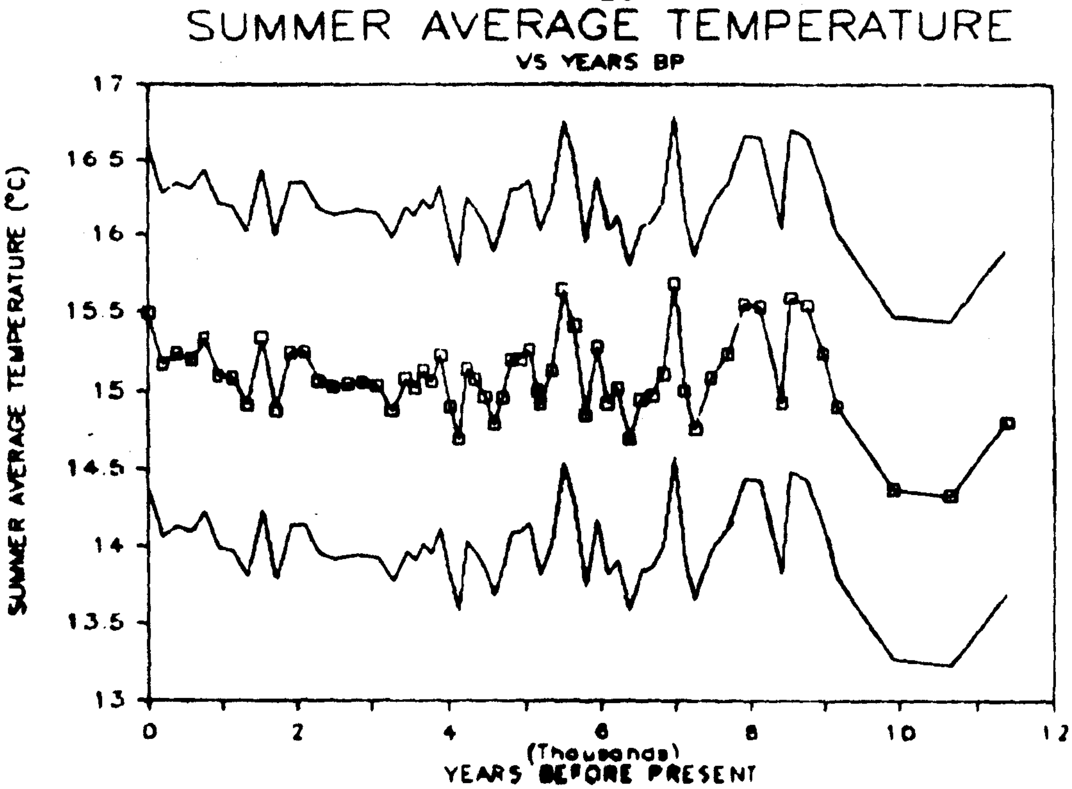

Figure 6. Summer average temperature curve

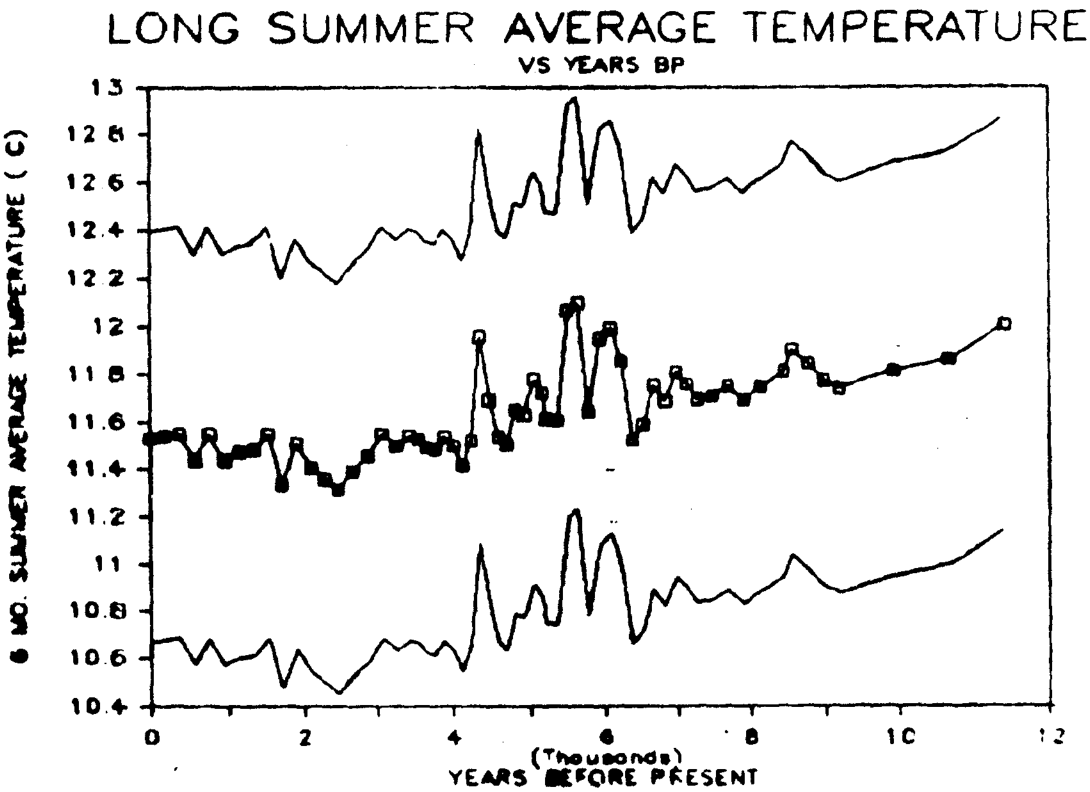

Figure 7. Long summer average temperature curve.

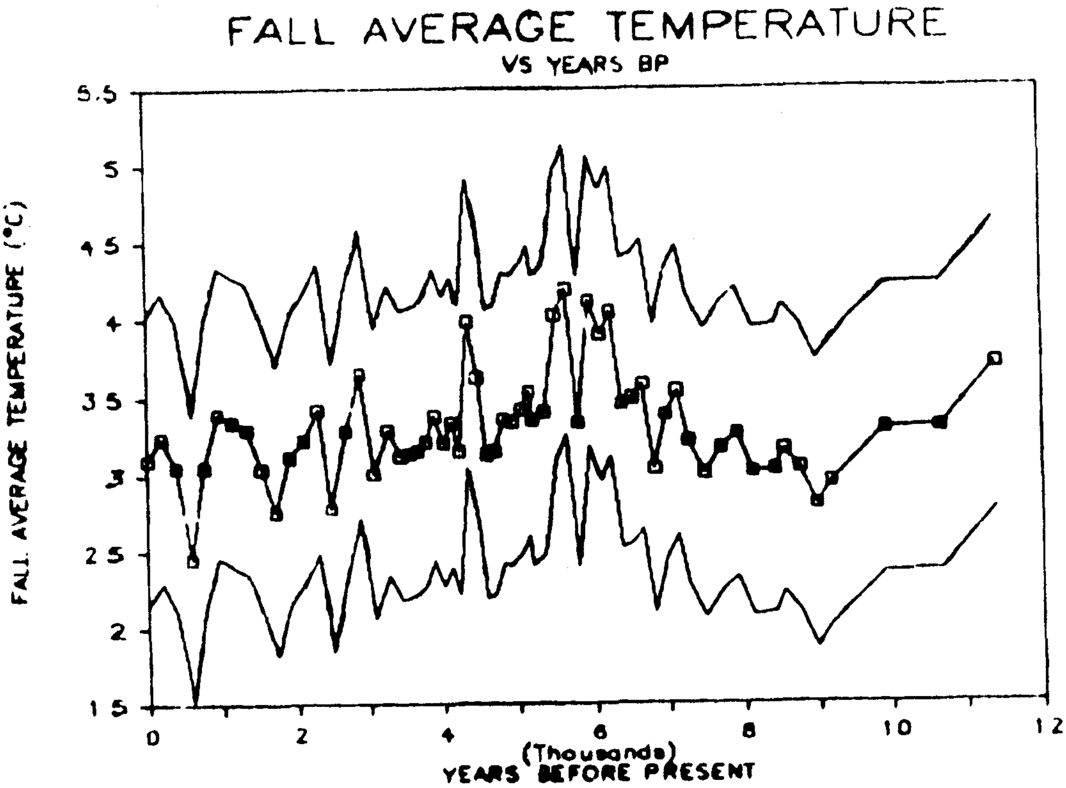

Figure 8. Fall average temperature curve

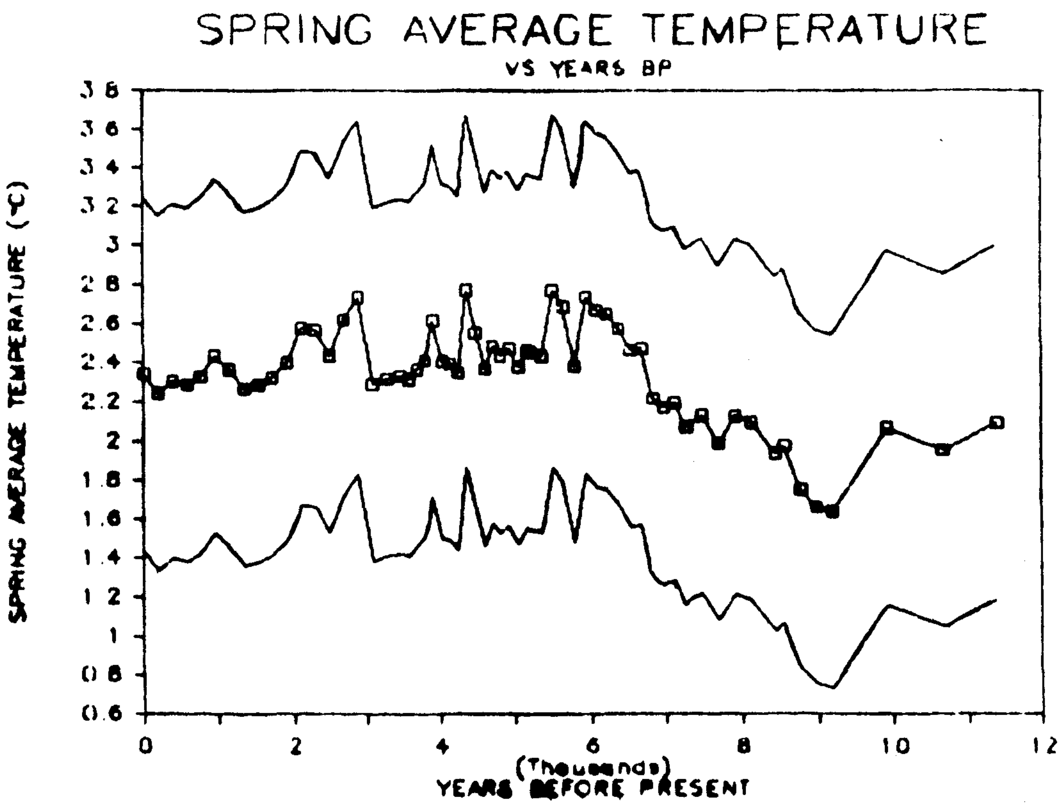

Figure 9. Spring average temperature curve

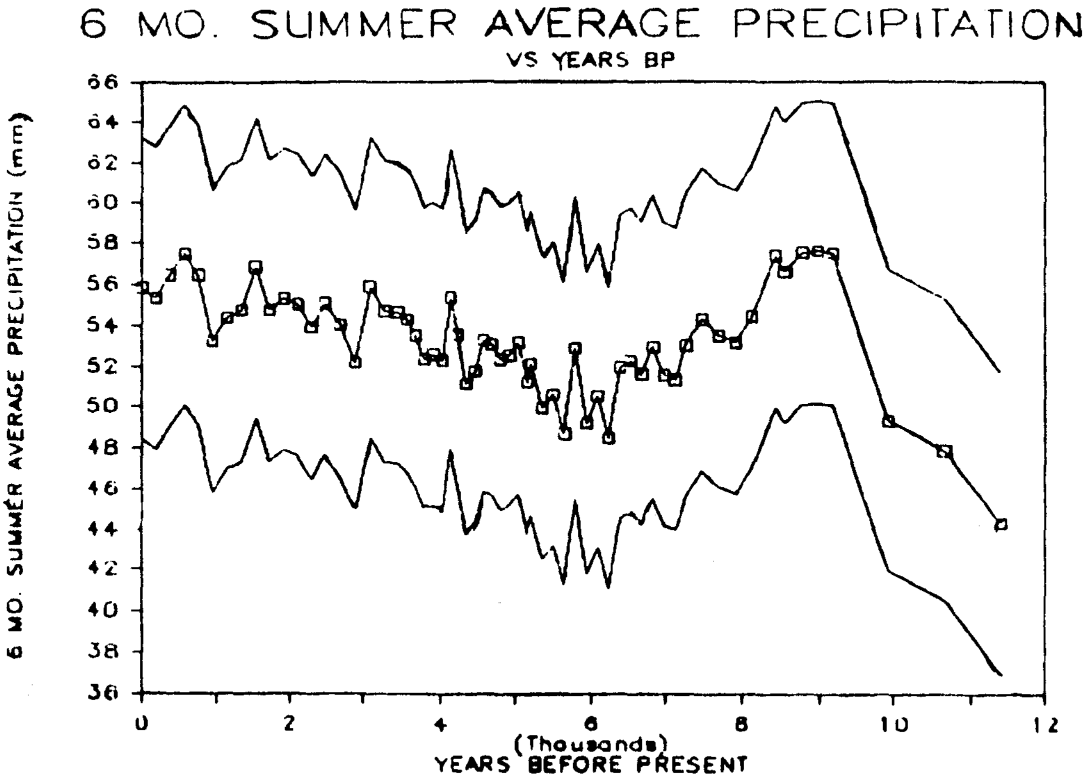

Figure 10. Long summer average precipitation curve

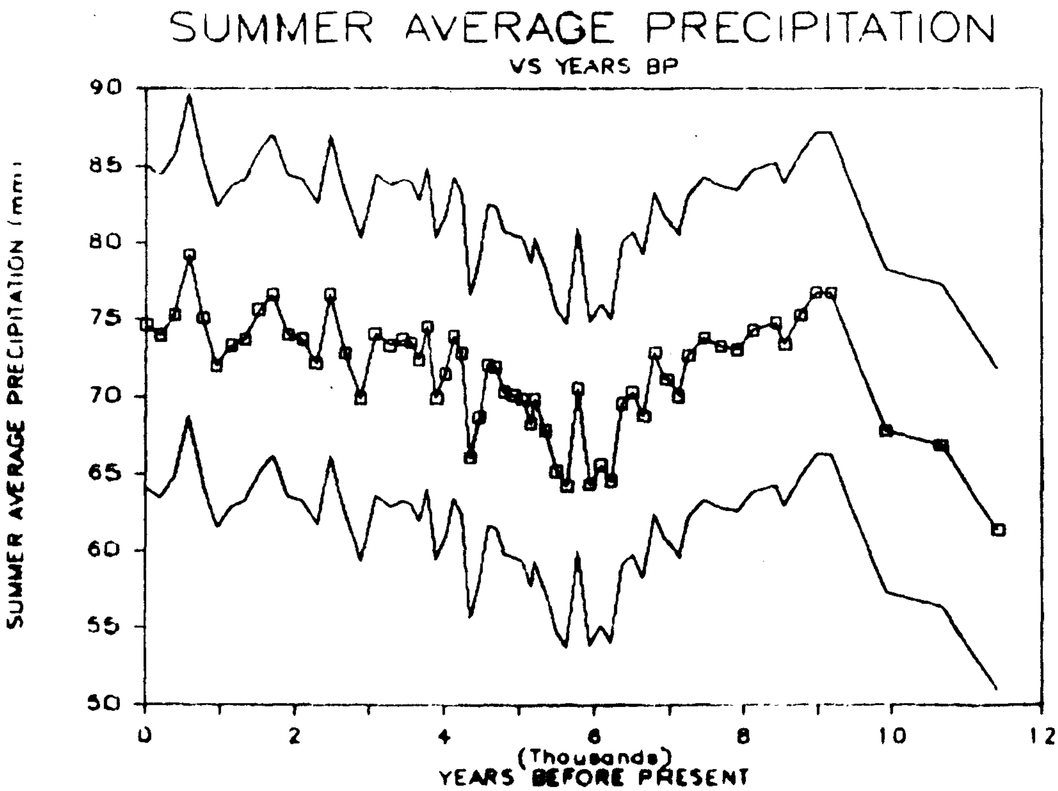

Figure 11. Summer average precipitation curve

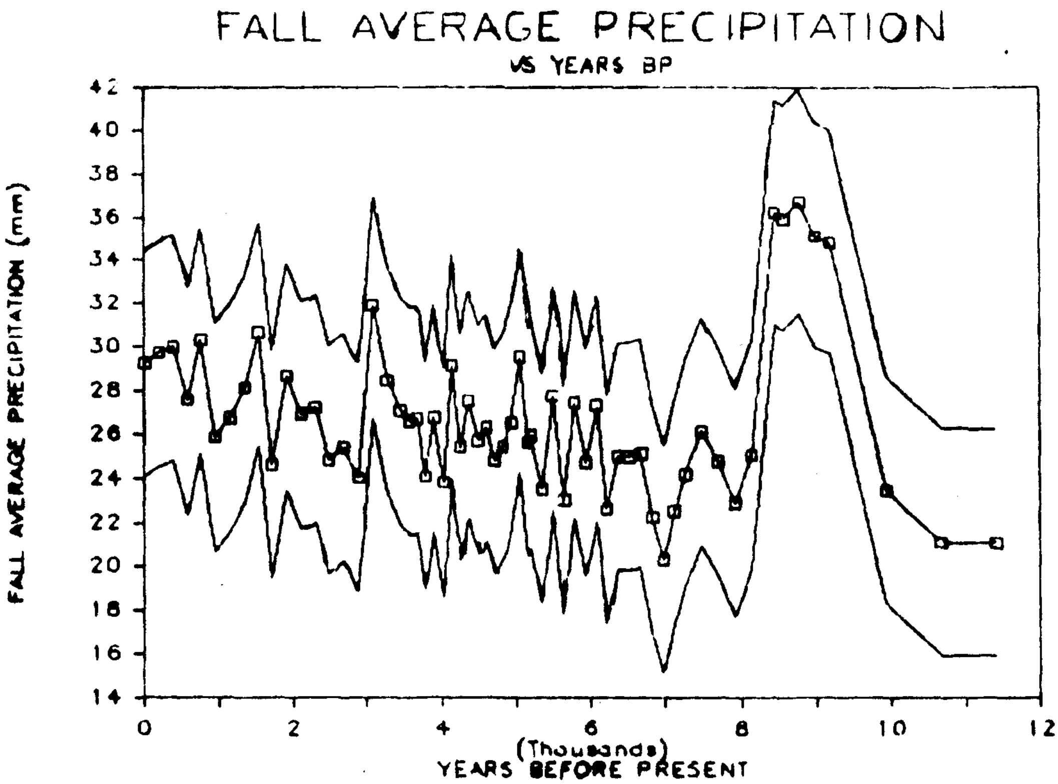

Figure 12. Fall average precipitation curve

DISCUSSION

In broad terms, the results of the transfer functions suggest that warm and dry conditions existed in central Alberta during the mid-Holocene. It must, however, be determined whether or not these curves are believable and do in fact accurately reflect climatic conditions in this area during the mid-Holocene. The precipitation and the tenperature curves will be discussed to determine their validity.

Temperature

The fall and winter temperature curves provide the most significant results and these both indicate increased temperatures during the mid-Holocene. To accept this result at face value one would have to assume that winter temperatures would somehow have to be controlling the present distribution of plants. This seems unlikely since plants are dormant during this season.

The fall temperature curve must also be questioned. It is also unlikely that fall temperatures are controlling plant distribution. The only way in which this temperature variable might affect the present plant distribution would be if higher fall temperatures are causing increased moisture stress.

The summer and spring temperature curves do not demonstrate a significant increase in temperature over the Holocene. This is inconsistent with the Milankovitch theory as well as the results of others (Ritchie, 1983; MacDonald and Ritchie, in press; Lichti-Federovich, 1970; Matthews et al., in press; Vance et al. 1983; Ritchie et al., 1983).

It is probable that the temperature estimate derived from the transfer functions are not truely representative of climatic conditions in central Alberta during the mid-Holocene. The reasons for this may lie in practical and theoretical problems inherent in this approach.

Several authors have put forth reasons as to why there are problems with use of transfer functions to predict paleoclimates. Bryson (1985) has presented several assumptions for paleoclimate reconstructions which may be violated. One is the assumption that climate is the only factor controlling species distributions and that all biotic boundaries are determined by standard climatic parameters when other factors such as photoperiod may be important. Also the problem of what constitutes an analagous climate arises. As Bryson points out, places exist which have similar precipitation and temperature regimes which by no means have the same general climate. Bryson (1985) also states that temperature and precipitation are not independant and should not be treated as such since for example, wetter might give the same effect as cooler within limits since evapostranspiration is in part a function of temperature.

The basic assumption of this approach to reconstructing past climates is that of methodological uniformitarianism - namely that modern day observations and relationships can be used as a model for past conditions and that the relationships betwen plants and climate have not changed with time (Birks,1981). Birks cites a number of reasons as to why these assumptions may be violated, bringing to bear such things as correlations between climate variables, inaccurate measures of the actual climate a plant experiences and the fact that the relationship of a species to climate may change within the range of species due to interactions between climate variables. Birks also states that if during a period of stability, species distributions do reach an equilibrium with climate, it is unknown whether an equilibrium ever exists and if it does, how long it takes to be attained. Material taken from Davis (1976) indicates that migration rates may prevent species from attaining an equilibrium with climate. For example, with the recession of the Laurentide ice sheet, areas may have become available suitable for colonization by certain plant taxa which were unable to migrate from their refugia fast enough to take advantage of this situation. Davis also suggests the possible development and influence of soils on plant taxa during the Holocene.

Practical problems associated with this particular project involve the sample size and present controls on vegetation in the Lofty Lake area. A larger sample size

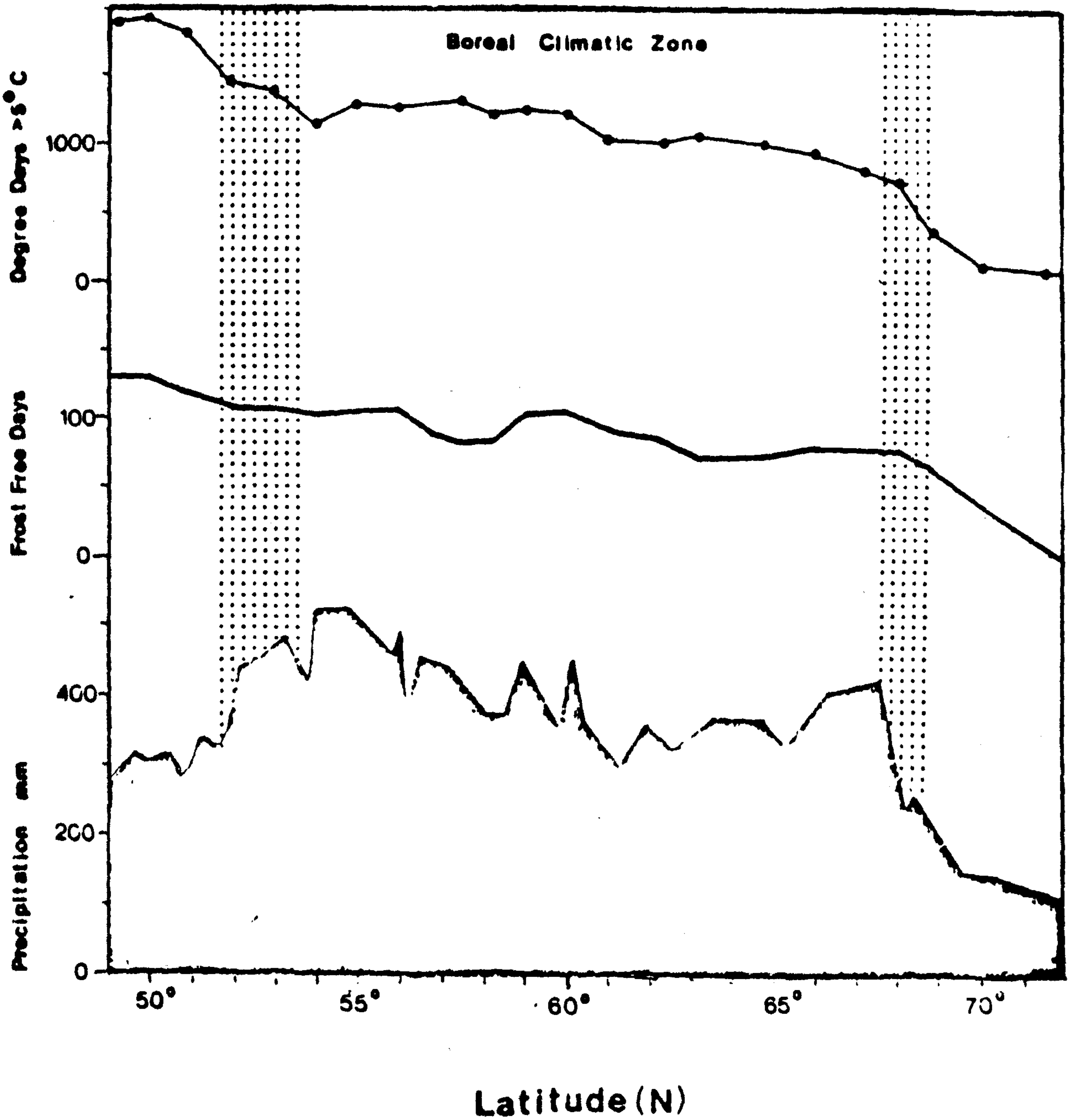

Figure 13. The latitudinal distribution of degree days above 5° C, frost free days and precipitation along a broad transect from southern Alberta to the Mackenzie Delta region on the Arctic Coast (data from Environment Canada, 1982a,b).

would decrease the size of the confidence intervals and thus increase the significance of the spring and summer curves.

In this region of Alberta there is not a great deal of variation of summer temperature with latititude (Figure 13) so spring and summer temperature do not exert as strong a control on vegetation as precipitation. Since the transfer function is based on the modern relationship between summer temperature and pollen rain, they are not likely to be sensitive to the impact of past variation in summer temperature due to this weak modern relationship.

Precipitation

The fall and summer precipitation curves are significant and indicate decreased precipitation during the mid-Holocene. Figure 13 indicates that precpitation varies significantly over the southern boundary of the boreal forest where Lofty Lake is located. This indicates that a strong precipitation control probably exists in the region so the transfer functions constructed reflects this strong relationship and thus provides potentially sensitve and significant precipitation curves. This is expected since plants are highly responsive to drought stress. A combination of low precipitation and high summer temperatures can produce moisture deficiencies over large parts of the province (North, 1976). Forested areas are not usually deficient in moisture but the boreal forest appears to have little of any water surplus North,1976) and many of the dominant tree species are intolerant of water deficits during their early development and the seedling stage of growth when the roots are being developed are particularly intolerant of drought.

A mechanism which would explain the decrease of precipitation in the mid- Holocene is the change in circulation patterns which occured during this period.

Harrison and Metcalfe (1985) used variations in lake level during the Holocene in North America to determine changes in atmospheric circulation patterns. These hypothesized changes in circulation patterns help to interpret the precipitation curves yielded from the hypsithermal history of Lofty Lake.

Firstly the general circulation patterns of North America must be briefly discussed.

In the Winter, the displacement of the Equatorial Trough and the zonal Westerlies causes Arctic air which is cold and dry to dominate Alberta and much of Alberta and North America and thus pacific air is unable to penetrate in past this continental stable air. In the summer, the Equatorial Trough and the zonal Westerlies move northwards and thus the Arctic airmass moves northwards accordingly (Harrison and Metcalfe, 1985). This allows for penetration of the warmer pacific and maritime tropical air mass into the continental interior. Although the Cordillera modifies the Pacific air to a degree, pacific air can penetrate quite deeply into the Albertan interior. Since there are significant contrasts in the moisture content of these airmasses, the distribution of these over the continent can be a major determinant of precipitation (Metcalfe and Harrison, 1985).

A well developed arid zone had formed over North America by 6000 BP from 37-57 N which encompasses the Lofty Lake site (Harrison and Metcalfe, 1985). The warm and dry period indicated by the curves probably further poleward displacement of the frontal zone between the Arctic and Pacific air masses probably to North of 56 N which was likely its most northern position (Harrison and Metcalfe,1985). The dominance of Arctic air over this region was replaced by the dominance of warm dry Pacific air. It is also possible that the predominance of Pacific air masses over the mid continent may have blocked the penetration of moist tropical maritime air into the region at around 6000 BP.

These above changes in circulation patterns are the cause of the dry period in the mid-Holocene recorded in the stratigraphy of Lofty Lake. The return to present day conditions was marked by displacement of the Arctic Front southward again to at least 51°N (Metcalfe and Harrison, 1985).

On a more local scale, the eastern foot of the Cordillera is a strongly cyclogenetic belt and as each synoptic scale trough arrives from the west, an organized low centre forms somewhere in the lee of the mountains (Hare and Bryson, 1974). These Alberta lows are important throughout the year and are the main sources of precipitation west of the 90th meridion (Hare and Bryson, 1974). With the displacement of the Equatorial Trough and the Westerlies northward these Alberta lows may also be displaced or the cyclogenesis may have been weakened somehow, thus reducing precipitation in the area. Also, strong and persistent maxima exist between 50°N and 59°N so a disturbance of these would very likely have produced an effect in the Lofty Lake region. The Alberta lows involve the Arctic front in their circulation as they move eastward (Hare and Bryson, 1974) so it is logical to assume that a displacement of the Arctic Front would affect the Alberta Lows.

During the mid-Holocene, the decreased dominance of the Arctic front allowing further penetration of Pacific air into Alberta may have increased the incidence of Chinook winds which in turn would increase mean temperature and decrease humidity (thus causing the curves to indicate a decrease in preicipitation since this would effectively increase the soil moisture deficit). Finally, the broad, warm sectors of Pacific air typical of the Alberta Lows move eastward across the plains and precipitation falls through the wedge of colder air north of the fronts involved so dispacement of the wedge north effectively reduces precipitation where this phenomona normally occurs.

The suggestion of a dry mid-Holocene episode by the precipitation curves is supported by the work of others who also determined the existence of drier conditions during this time (Matthews et al., in press; MacDonald and Ritchie, in press; Vance et al., 1983; White and Mathewes, 1982; Last and Schweyen, 1985).

The precipitation curves do seem to indicate that precipitation was in fact lower during the mid-Holocene. However, the problem arises as to whether or not the curve's indication of low precipitation is a function of actually decreased precipitation at this time or whether it is also a response to the increased temperatures. Increased insolation would of course result in increased evaporation and evapotranspiration thus causing the vegetation to react to this in the same way they would react to a decrease in precipitation since these factors would result in decreased soil moisture. Vegetation is highly responsive to soil moisture since it is neccessary for the germination and growth of any seeds and with deficient moisture, a plant cannot obtain enough nutrients in solution to maintain its tissues (North,1974).

<u>Summary</u>

Because of the theoretical and practical problems discussed above, the temperature curves derived from the transfer functions can not be accepted as representative of conditions during the mid-Holocene in the Lofty Lake region.

The precipitation curves are somewhat more reasonable although it cannot be determined whether they actually reflect only decreased precipitation or are influenced by increased evapotranspiration as a result of increased temperatures.

CONCLUSIONS

1. Calibration functions for the Western Interior of Canada were constructed and were applied to fossil pollen from Lofty Lake in order to obtain paleoclimate estimates of conditions during the Holocene.

2. An attempt was made to construct calibration functions for spring, fall, summer, and winter precipitation; spring, fall, summer and winter temperatures as well as degree days frost free days, and standard deviations for January and July temperatures and precipitation. Estimates were obtained for winter temperature (six month average and three month average), summer average temperature (six month average and three month average), spring average temperature, fall average temperature, fall average precipitation, and summer average precipitation (six month and three month).

3. The temperature curves indicate a period of increased winter and fall warmth around 6000 BP. The summer and spring palaeotemperature curve suggest no change over the mid-Holocene. The palaeoprecipitation estimates indicate decreased summer and fall precipitation.

4. This study highlights the problems of the pollen-climate transfer function approach. Although this approach is attractive since it provides actual quantitative estimates of palaeoclimates, a number of theoretical and practical problems inherent in this method cause the paleotemperature estimates to be invalid.

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Appendix 1: CANDIDATE TAXA FOR INCLUSION IN THE CALIBRATION FUNCTIONS

FALL AVERAGE TEMPERATURE

√PICEA
√BETULA
√ALNUS
√CHENOAM
√COMPOSITAE
√GRAMINEAE

SPRING AVERAGE TEMPERATURE

PICEA
√BETULA
√ALNUS
CHENOAM

SUMMER AVERAGE TEMPERATURE

√PICEA
√BETULA
√ALNUS
√SALIX
CHENOAM
√COMPOSITAE

WINTER AVERAGE TEMPERATURE

√PICEA
√BETULA
√ALNUS
√CHENOAM
√COMPOSITAE
√GRAMINEAE

SIX MONTH SUMMER AVERAGE TEMPERATURE

√PICEA
√BETULA
√ALNUS
√CHENOAM
√COMPOSITAE
√GRAMINEAE

SIX MONTH WINTER AVERAGE TEMPERATURE

√PICEA
√BETULA
√ALNUS
√CHENOAM
√COMPOSITAE
√GRAMINEAE

SUMMER AVERAGE PRECIPITATION

√PICEA
√BETULA
√ALNUS
√ARTEMISIA
√CHENOAM
√COMPOSITAE
√GRAMINEAE

SIX MONTH SUMMER AVERAGE PRECIPITATION

√PICEA
√BETULA
√ALNUS
√ARTEMISIA
√GRAMINEAE

FALL AVERAGE PRECIPITATION

√PICEA
√BETULA
√ALNUS
√ARTEMISIA
√CHENOAM

Appendix 2: CORRELATION COEFFICIENTS FOR UNTRANSFORMED TAXA (significant at alpha=.05)

	FAT	SRAT	WAT	SAT	LWAT	LSAT	SAP	WAP
PICEA	-.73	-.61	-.76	-.61	-	-.64	.79	.62
PINUS	-	-	-	-	-	-	-	-
BETULA	.71	.60	-.70	.60	-.68	-	.74	-
ALNUS	-.70	.63	-.68	-.63	-.66	-.64	.72	-
SALIX	-	-	-	-	-	-	-	-
ARTEMISIA	-	-	-	-	-	-	-	-
CHENOAM	.94	.82	.83	.91	.89	.91	.87	-
COMPOSITAE	-	-	-	-	-	-	-	-
GRAMINEAE	.59	-	.68	-	.65	.65	-.64	-
CYPERACEAE	-	-	-	-	-	-	-	-
POPULUS	-	-	-	-	-	-	-	-

FAT fall average temperature
SRAT spring average temperature
WAT winter average temperature
SAT summer average temperature
LWAT long winter average temperature
LSAT long summer average temperature
SAP summer average precipitation
WAP winter average precipitation

'-' indicates $-.50<r<.50$

CORRELATION COEFFICIENTS FOR UNTRANSFORMED TAXA
CONTINUED
(significant at alpha = .05)

	LSAP	LWAP	FAP	SRAP	JAT	JAP	JUP	JUT	DD	FF
PICEA	.82	-	-	-	-.78	-	-.70	-.73	-.68	-.59
PINUS	-	-	-	-	-	-	-	-	-	-
BETULA	.75	-	.60	-	-.63	-	-.64	-.74	-.66	-.63
ALNUS	.73	-	.61	-	-	-	-	-.73	-.71	-.69
SALIX	-	-	-	-	-	-	-	-	-	-
ARTEMISIA	.58	-	.53	-	-	-	-	-	-	-
CHENOAM	.79	-	-	-	.81	-	.84	.83	.81	-
COMPOSITAE	-	-	-	-	-	-	-	.63	-	-
GRAMINEAE	-.64	-	-.63	-	.70	-	.70	-	-.65	-
CYPERACEAE	-	-	-	-	-	-	-	-	-	-
POPULUS	-	-	-	-	-	-	-	-	-	-

LSAP long summer average precipitation
LWAP long winter average precipitation
FAP fall average precipitation
SRAP spring average precipitation
JAT January average temperature
JUT July average temperature
JAP January average precipitation
JUP July average precipitation
DD growing degree days
FF frost free days

'-' indicates $-.50<r<.50$

Appendix 3: CORRELATION COEFFICIENTS FOR TRANSFORMED TAXA
(significant at alpha=.05)

	FAT	SRAT	WAT	SAT	LWAT	LSAP	SAP	WAP	LSAP
$\sqrt{\text{PICEA}}$	-.78	-.62	-.78	-.84	-.77	-.70	.84	.57	.85
$\sqrt{\text{PINUS}}$	-	-	-	-	-	-	-	-	-
$\sqrt{\text{BETULA}}$	-.82	-.64	-.79	-.69	- .79	-.74	.83	-	.81
$\sqrt{\text{ALNUS}}$	-.79	-.62	-.72	-.72	-.72	-.76	.81	-	.78
$\sqrt{\text{SALIX}}$	-	-	-.51	-	-	-	-	-	-
$\sqrt{\text{ARTEMISIA}}$	-	-	-	-	-		-.59	-	-.68
$\sqrt{\text{CHENOAM}}$	.94	.83	.87	.79	.90	.88	-.91	-	-.85
$\sqrt{\text{COMPOSITAE}}$	.58	-	.52	.56	.53	.58	-.66	-	-.65
$\sqrt{\text{GRAMINEAE}}$	.60	-	.68	-	.65	-	-.68	-	.68
$\sqrt{\text{CYPERACEAE}}$	-	-	-	-	-	-	-	-	-
$\sqrt{\text{POPULUS}}$	-	-	-	-	-	-	-	-	-

FAT Fall average temperature
SRAT Spring average temperature
WAT Winter average temperature
SAT Summer average temperature
LWAT Long winter average temperature
SAP Summer average precipitation
WAP Winter average precipitation
LSAP Long summer average precipitation

'-' indicates $-.50<r<.50$

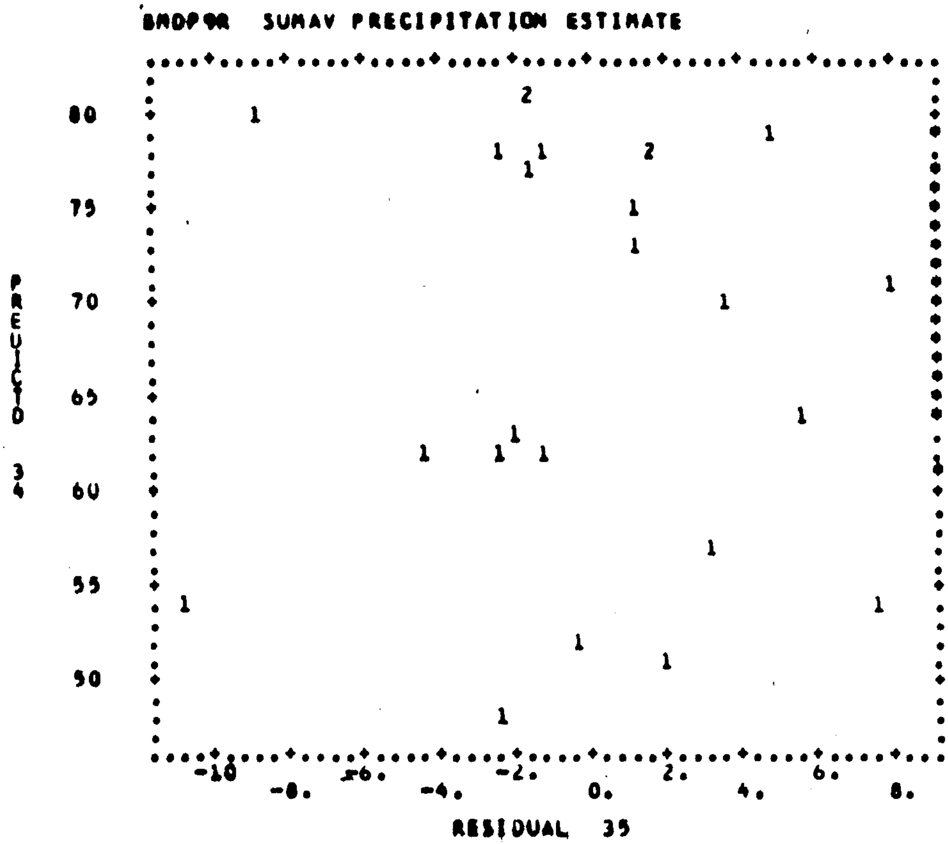
CORRELATION COEFFICIENTS FOR TRANSFORMED TAXA
CONTINUED
(significant at alpha = .05)

	LWAP	FAP	SAP	JAT	JUT	JUP	JAP	DD	FF
$\sqrt{\text{PICEA}}$	–	.81	–	–.80	–.73	–.56	–	–.71	–.56
$\sqrt{\text{PINUS}}$	–	–	–	–	–	–	–	–	–
$\sqrt{\text{BETULA}}$	–	.69	–	–.79	.73	.81	–	–.75	–.60
$\sqrt{\text{ALNUS}}$	–	.63	–	–.73	–.73	.83	–	–.79	–.62
$\sqrt{\text{SALIX}}$	–	–	–	–	–	–	–	–	–
$\sqrt{\text{ARTEMISIA}}$	–	–.58	–	–	–	–	–	–	–
$\sqrt{\text{CHENOAM}}$	–	–.64	.50	.85	.83	–.87	–	–.87	.52
$\sqrt{\text{COMPOSITAE}}$	–	–.56	–	.53	.61	–.58	–	–	–
$\sqrt{\text{GRAMINEAE}}$	–	–.69	–	.70	–	.70	–	–	–
$\sqrt{\text{CYPERACEAE}}$	–	–	–	–	–	–	–	–	–
$\sqrt{\text{POPULUS}}$	–	–	–	–	–	–	–	–	–

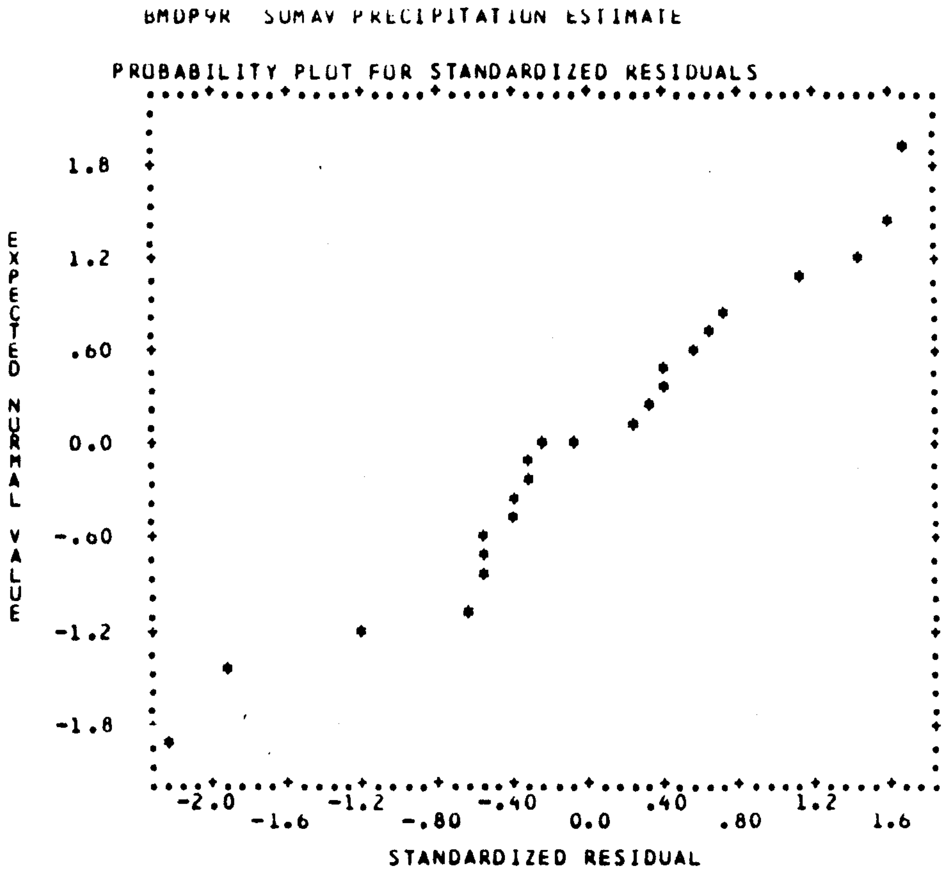
LWAP Long winter average precipitation
FAP Fall average precipitation
SAP Summer average precipitation
JAT January average temperature
JUT July average temperature
JAP January average precipitation
JUP July average precipitation
DD Degree days
FF Frost Free days

'–' denotes $-.50<r<.50$

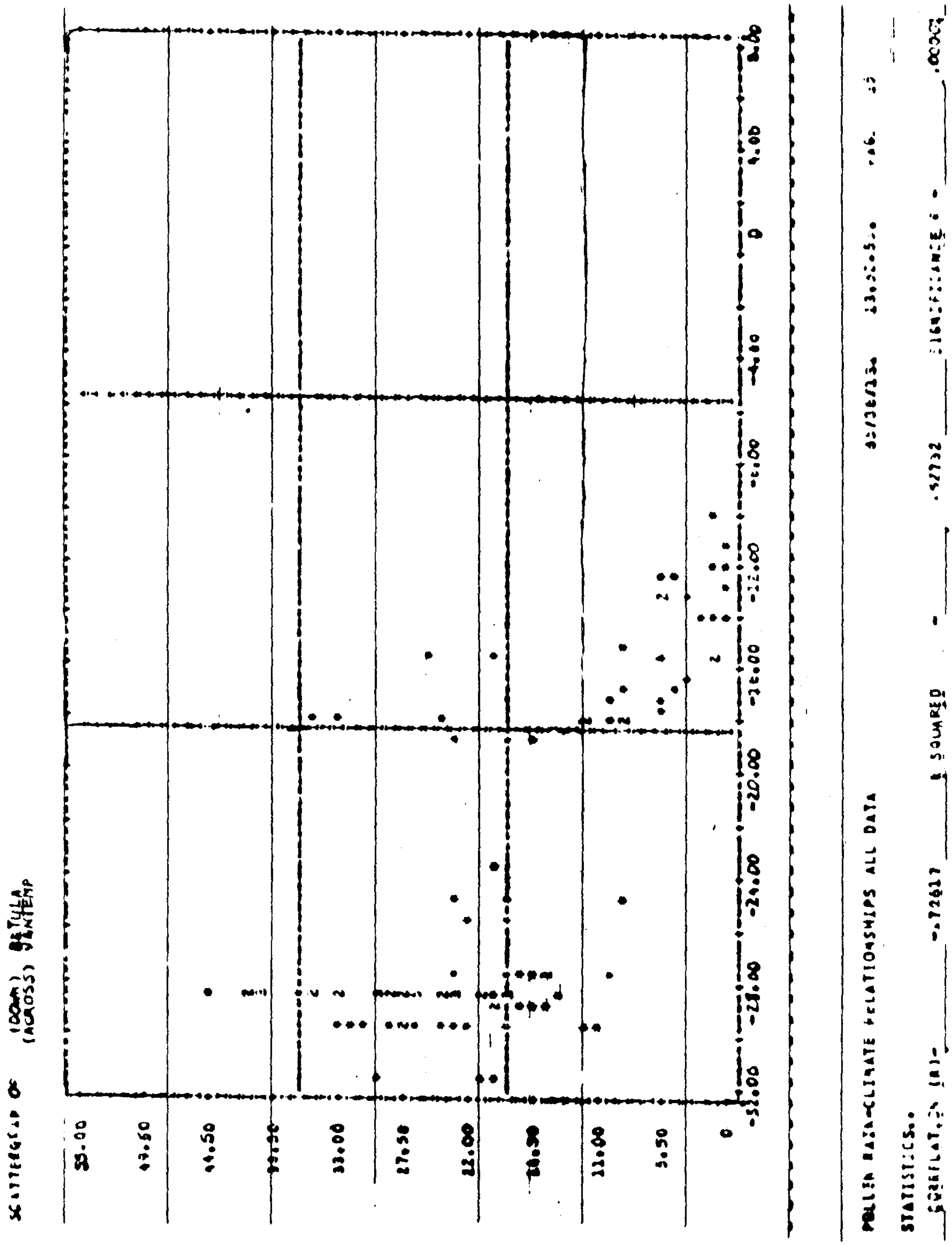
Appendix 4. Predicted values vs. residuals for the Summer average precipitation estimate.



Appendix 5. Probability plot for standardized residuals for for the summer average precipitation estimate.

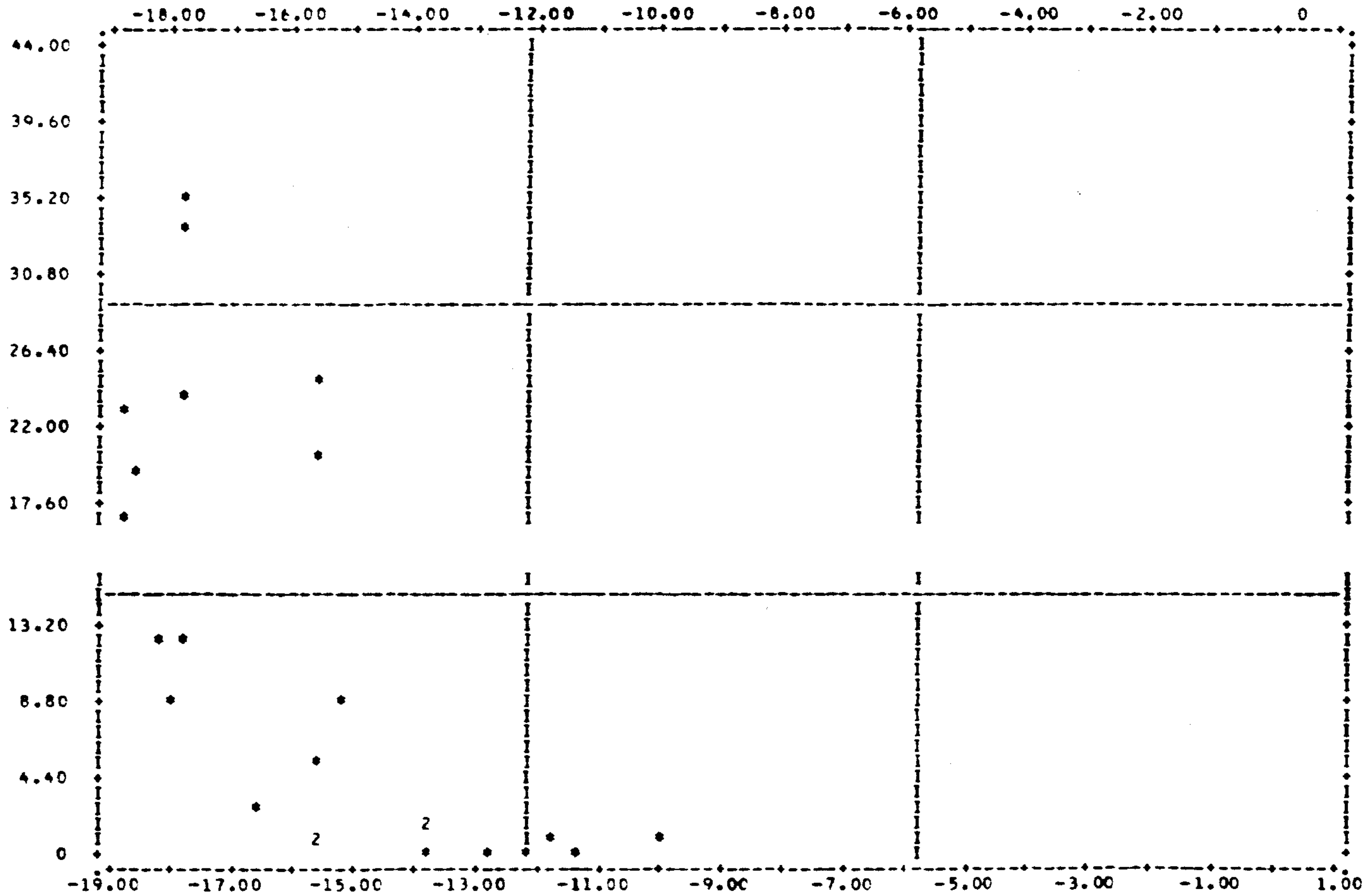


Appendix 6. Scattergrams of <u>Betula</u> vs. January temperature



Untransformed Betula

SCATTERGRAM OF (DOWN) BETULA
(ACROSS) JANTEMP



POLLEN RAIN-CLIMATE RELATIONSHIPS 3RD DROP 85/11/04. 13.28.35. PAGE 31

STATISTICS..

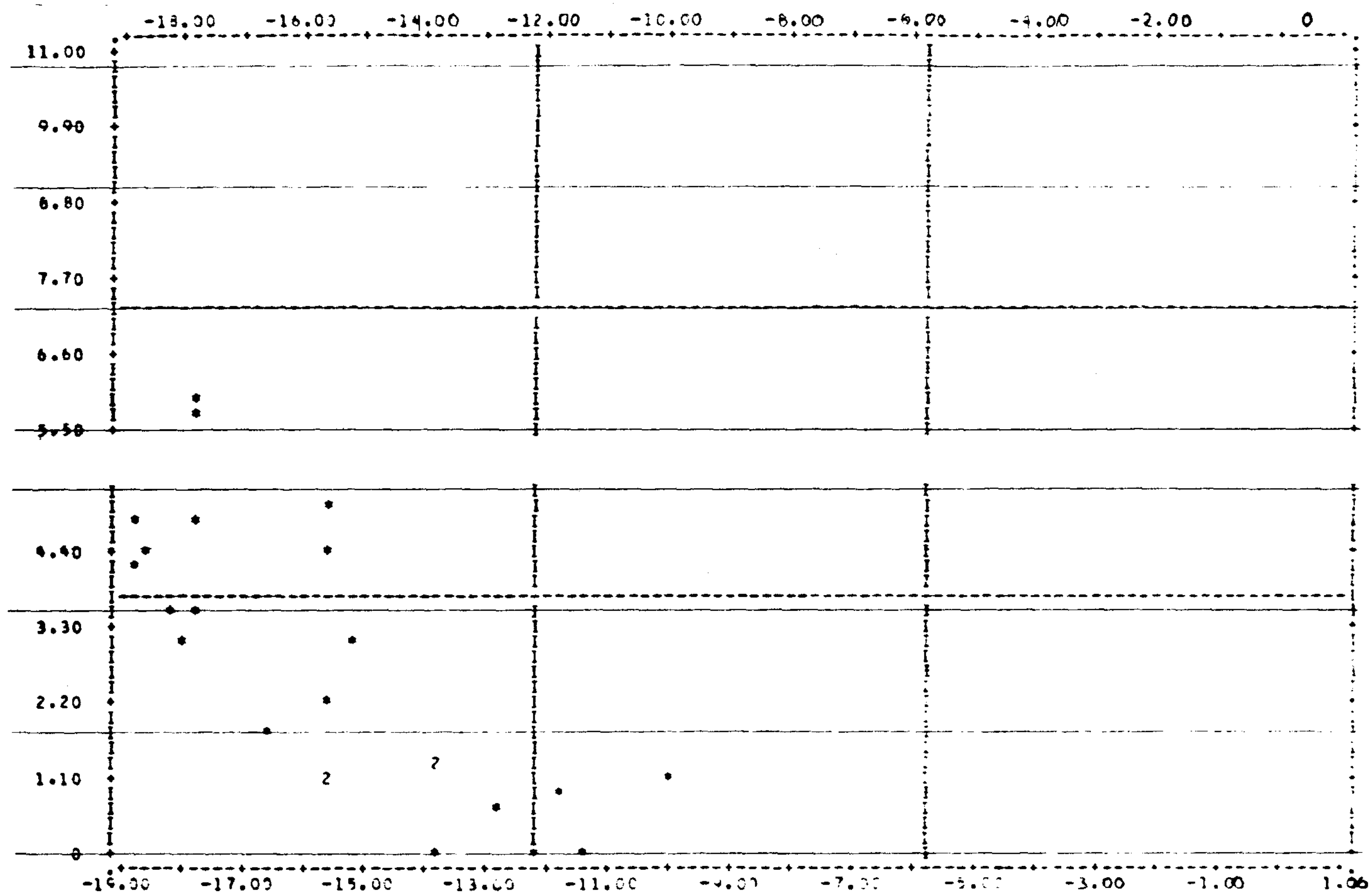
CORRELATION (R)-	-.69894	R SQUARED -	.48852	SIGNIFICANCE R -	.00014
STD ERR OF EST -	8.23040	INTERCEPT (A) -	-36.10161	STD ERROR OF A -	10.31585
SIGNIFICANCE A -	.00203	SLOPE (B) -	-3.00440	STD ERROR OF B -	.65542
SIGNIFICANCE B -	.00014				

Transformed Betula

POLLEN RAIN-CLIMATE RELATIONSHIPS 3RD DEEP

~~FILE NONAME (CREATION DATE = 85/11/13.)~~

SCATTERGRAM OF (DOWN) SQBETULA (ACROSS) JANTEMP



~~POLLEN RAIN-CLIMATE RELATIONSHIPS 3RD DEEP~~

STATISTICS..

CORRELATION (R)-	-.76877	R SQUARED -	.59101	SIGNIFICANCE -	.0001
STD ERR OF EST -	1.22225	INTERCEPT (A) -	-5.[illegible]477	[illegible] -	
SIGNIFICANCE A -	.[illegible]	SLOPE (B) -	-.58582	[illegible] -	
SIGNIFICANCE B -	.[illegible]				