Paleolimnological analysis of Culculz Lake, B.C -- Final Report
(March 2000)

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Fig. 2 Stratigraphic distribution of diatom taxa in the core from Culculz Lake.

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Appendix B: Summary of data used in calculating \(^{210}\)Pb dates and \(^{210}\)Pb output.
Appendix C: Summary of relative abundances of diatom taxa in Culculz Lake.

BACKGROUND

Culculz Lake was cored on October 5, 1999 by Rick Nordin and Bruce Carmichael. The core was retrieved using a modified K-B corer (internal diameter ~ 6.35 cm) from the deep basin. On shore the core was sectioned into 0.5-cm intervals into 120-ml plastic containers. Every other sample was shipped on ice to Queen's University where they were stored in our coldroom at 4°C. The containers were weighed to determine the total wet weight of sediment prior to subsampling for \(^{210}\)Pb analyses. Twenty intervals (every 2 cm) were subsampled for diatom and sixteen intervals for \(^{210}\)Pb analysis. Prepared samples for \(^{210}\)Pb analysis (see below) were sent to MYCORE Ltd.

METHODS

210-Pb Dating and Percent Organic Matter

The wet weight of the sediment was determined for all the subsections of the core that were shipped to Queen's. Sixteen subsamples of wet sediment from each core were weighed and oven-dried (24 hr at 105°C) and reweighed to determine percent water and dry weight of the sediment. Samples that were submitted for \(^{210}\)Pb analysis were ground to a fine dust by use of a pestle and redried overnight at 105°C. The weight of this dried sediment
was recorded to four decimal places after it was put in a tared plastic digestion tube for determination of $^{210}\text{Pb}$ activity that was shipped to MYCORE Ltd.

Percent organic matter for each of the 16 $^{210}\text{Pb}$ samples was determined using standard loss-on-ignition methods (Dean, 1974). A known quantity of dried sediment (recorded to four decimal places) was heated to 550°C for 2 hours. The difference between the dry weight of the sediment and the weight of sediment remaining after ignition was used to estimate the percent of organic matter in each sediment sample.

$^{210}\text{Pb}$ activities were estimated from determination of $^{209}\text{Po}$ and a tracer of known activity by alpha spectroscopy. Unsupported $^{210}\text{Pb}$ is calculated by subtracting supported $^{210}\text{Pb}$ (the baseline activity determined from bottom samples of the core) from the total activity at each level. The sediment chronology and sedimentation rates were calculated using the constant rate of supply (CRS) model (Appleby and Oldfield, 1978) from the estimates of $^{210}\text{Pb}$ activities and estimates of cumulative dry mass (Binford, 1990). See Appendix B for summaries of $^{210}\text{Pb}$ analyses by MYCORE (B-1), summary of $^{210}\text{Pb}$ calculations (B-1,2), and output from the CRS model (B-3).

### Diatom Preparation and Enumeration

Slides for diatom analysis were prepared using standard techniques (Cumming, Wilson, Smol and Hall, 1995). Briefly, a small amount of wet sediment was suspended in a 50:50 (molar) mixture of sulfuric and nitric acid in a 20-ml glass vial for 24 hr. prior to being submersed at 70°C in a hot water bath for 5 hr. The remaining sediment material was settled for a period of 24 hr, at which time the acid above the sample was removed. The sample was rinsed with distilled water and allowed to settle once again for 24 hrs. The procedure was repeated approx. 10 times until the sample was acid free (litmus test). The samples were settled onto coverslips in a series of four 100% dilutions, which when dry, were mounted onto glass slides using a high-resolution mounting media called Naphrax®. For each sample, at least 400 diatom taxa were enumerated with a Leica DMRB microscope equipped with DIC optics at 1000X magnification (Numerical Aperature of objective = 1.3). These analyses were based on the references of Krammer and Lange-Bertalot (1986, 1988, 1991a,b), Patrick and Reimer (1966, 1975) and Cumming et al. (1995).

### Cluster Analysis

A depth-constrained cluster analysis was run on the diatom assemblages in the core to provide an unbiased assessment of changes in diatom assemblages through time. A squared chord distance was used as the similarity coefficient between samples in the cluster analysis. Zones based on this clustering
algorithm were placed on the diatom stratigraphy to represent zones of similar diatom assemblages (dashed line on Fig. 2).

**Diatom-based Reconstructions of Total Phosphorus**

Inferences of total phosphorus from the diatom assemblages in the core are based on a phosphorus model developed from 111 freshwater lakes from the 219 lakes sampled by Wilson, Cumming & Smol (1996). This model is based on estimates of the optima of taxa from weighted-averaging regression on non-transformed relative percentage data. The coefficient of determination ($r^2$) of this model is 0.66, and the jackknifed $r^2$ is 0.47. This model is superior to the earlier models developed by Reavie, Hall & Smol (1995) for several reasons including its better predictive ability and the larger number of samples which provide more analogs for downcore reconstructions.

The total phosphorus inferences (Fig. 1E) were critically assessed to determine: 1) if they tracked the main direction of variation in the diatom species assemblages (Fig. 1D); and 2) to assess if the assemblages encountered in the core are well represented in the modern-day samples (Fig. 1F). If the diatom-based phosphorus reconstruction matches the main direction of variation in the diatom assemblages downcore, then we can be fairly confident that the diatoms are tracking changes correlated to phosphorus. If the correlation between the main direction of variation and the diatom-inferred phosphorus values is weak or nonexistent, then other environmental variables (e.g. pH, conductivity, turbulence, etc), or interactions between environmental variables, are likely responsible for the observed changes in diatom assemblages (i.e. other environmental variables besides changes in phosphorus are responsible for the observed changes).

**Determination of the Main Direction of Variation**

The main direction of variation in the diatom assemblages downcore was determined from the first axis scores from a principal components analysis (PCA) ordination using non-transformed species abundance data. A PCA was chosen to represent the main direction of variation of the diatom assemblages in this core based on the small gradient length (< 1.5 sd units) obtained in an initial detrended correspondence analysis (DCA) ordination.

**Analog Analysis of Diatom Assemblages**

The reliability of the downcore total phosphorus inferences assumes that the diatom assemblages encountered downcore are well represented in our modern diatom assemblages. To determine if appropriate analogs existed for the core samples, we determined which samples in our present-day dataset of 111 lakes most resembled each of the downcore samples. This determination was
based on a squared chord dissimilarity coefficient between all species found in each of the core samples. The best match between downcore and modern samples was compared with the distribution of best match between modern samples. Any downcore sample that was more dissimilar than 80% of the modern distribution were deemed to be a 'poor analog'. Similarly, any downcore sample that was more dissimilar than 95% of the modern distribution were deemed to have 'no analog' in our present-day dataset. If the downcore assemblages have good representation in modern samples, more confidence can be placed in the reconstruction. If modern analogs do not exist or are poor, then caution must be placed in reconstructions from these downcore samples.

RESULTS AND DISCUSSION

\(^{210}\text{Pb}\) Profile, Sedimentation Rates and Organic Matter

The \(^{210}\text{Pb}\) profile from Culculz Lake shows the expected exponential decay with core depth with the exception of a small decrease in activity at the top of the core (Fig. 1A). Overall, the \(^{210}\text{Pb}\) profile from this lake indicates an intact an undisturbed sediment core was obtained from this lake and that sedimentation rates have been relatively slow (~1 mm/yr). Furthermore, only small variations in sedimentation rates and changes in organic matter have occurred over the time period represented by this core (Figs. 1B, 1C). The results of the time/depth calculations can be found in Appendix B3. The most likely explanations for the decrease in \(^{210}\text{Pb}\) activity at the top of the core include: a minor increase in sedimentation rate that could cause a slight dilution of the \(^{210}\text{Pb}\) activity, and/or sediment mixing. The CRS model assumes that decreases in \(^{210}\text{Pb}\) activities are due to dilution from increased sedimentation (Fig. 1B). In summary, the variations in both sedimentation rates and changes in organic matter are small and variable throughout this core (Figs. 1B and 1C).

Diatom Assemblage Changes and Analyses

Approximately 100 diatom taxa were encountered in the sediment core from Culculz Lake (Appendix C-1). Changes in the diatom assemblages indicate that this lake has only undergone minor changes in species composition over the last 300 years. Cluster analysis suggests the changes in diatom assemblages through time can be divided into two primary zones (Fig. 2).

Prior to c. 1865 (Fig. 2, Zone B), the diatom assemblage is dominated by eutrophic planktonic taxa (e.g. \textit{Stephanodiscus minutulus}, \textit{S. parvus}, and \textit{S. hantzschii}). Consequently, inference of pre-1900 TP values range from ~23 to 34 μg/L. Since c. 1865,
there have been decreases in the abundance of S. parvus, and
small increases in the abundance of Asterionella formosa,
Fragilaria crotonensis, F. capucina, and S. hantzschii (Fig. 2,
Zone A). These floristic changes suggest that the lake has
varied in nutrient status over the last 150 years, but no more
than prior to human settlement (Fig. 1E).
PCA axis 1 scores (Fig. 1D) account for 54% of the variation
diatom taxa in this core. The coefficient of determination
between the PCA axis 1 scores (Fig. 1D) and the log TP inferences
(Fig. 1E) is low ($r^2 = 0.43$). Thus, the inferred changes in TP
are only weakly related to the main direction of variation in the
diatom assemblages. Based on the good representation of the core
diatom assemblages in the modern day samples (Fig. 1F), the TP
inferences are likely reliable. In summary, this lake has
historically had high concentrations of phosphorus and the recent
changes are within the range observed over the past 300 years.

References:

dates assuming a constant rate of supply of unsupported $^{210}\text{Pb}$

Binford, M.W. 1990. Calculation and uncertainty analysis of $^{210}\text{Pb}$
dates for PIRLA project lakes sediment cores. *Journal of
Paleolimnology* 3: 253-267.

Diatoms from British Columbia (Canada) Lakes and their
Relationship to Salinity, Nutrients and Other Limnological
Variables (with 248 figures, 6 tables and 1041 photos on 60
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York, 876 pp.

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Teil: Centrales, Fragilariaceae, Eunotiaceae. In H. Ettl,
G. Gärtner, J. Gerloff, H. Heynig & D. Mollenhauer (eds.),


Figure Captions

Figure 1. Summary diagram for the sediment core from Culculz Lake showing: A) total $^{210}$Pb activity from which the chronology of the core is based; B) the sediment accumulation rate; C) the change in the percent of organic matter in the core; D) the main direction of variation in the diatom assemblage data; E) diatom-based estimated late-summer total phosphorus; and F) analog analysis showing the dissimilarity between present-day and downcore samples (any sample that has a squared chord distance > 0.8 was determined to be a poor analog, whereas any sample with a squared chord distance greater than 1.1 was determined to have no analog in the modern dataset).

Figure 2. Stratigraphy of the dominant diatom taxa in the sediment core from Culculz Lake, B.C. (see Appendix C for a complete list of taxa and the relative percentage data). The diatom taxa are arranged in order of increasing late-summer total phosphorus (TP) optima which are indicated in parentheses for those taxa with known optima. The dotted lines separate the stratigraphy into two zones that were identified by a cluster analysis on the diatom assemblage composition that was constrained to the depth of the core samples (see text for details).
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