ASSESSMENT OF CHANGES IN TOTAL PHOSPHORUS IN NUKKO LAKE, B.C. : A PALEOLIMNOLOGICAL ASSESSMENT (March 2006)

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BACKGROUND

A 31.5-cm sediment core was retrieved from Nukko Lake with a modified K-B corer (internal diameter 5.08 cm) in February 2005 (54˚ 04.829' N; 122˚ 59.858' W). Samples were sectioned into 0.5-cm intervals, with the exception of the bottommost sample (27.5-31.5 cm), which was collected as a single sample. All samples were sent to PEARL at Queen's University on February 11, 2005 where they were stored in our coldroom at 4 ºC. All the samples were weighed to determine the total wet weight of sediment prior to subsampling for ^{210}Pb, loss-on-ignition and diatom analyses. Twenty intervals were subsampled for diatoms. Samples analyzed for diatom composition were approximately every 1.0 cm for the top 11.0 cm, then every 2.0 cm to 25.0 cm and then a final sample at 26.5cm. Sixteen intervals were analyzed for ^{210}Pb analysis by (see below) using gamma spectroscopy at PEARL, Queen's University.

METHODS

^{210}Pb Dating and Percent Organic Matter

Twenty samples for Nukko Lake were dried in the freeze drier at PEARL (24 hr. cycle). Dry weight of the sediment and percent water was determined. Dry sediment was then precisely weighed into a plastic tube for gamma spectroscopy. Sixteen samples were then sealed with epoxy and allowed to sit for two weeks in order for ^{214}Bi to equalize for determination of supported ^{210}Pb used in estimating core chronology. Activities of ^{210}Pb, ^{137}Cs and supported ^{210}Pb (via ^{214}Bi) were determined for each sample. These activities were then used to estimate the chronology of the core.

The activities (in disintegrations per minute/gram) of ^{210}Pb, ^{137}Cs and ^{214}Bi were determined using the procedures outlined in Schelske et al. (1994). Unsupported ^{210}Pb was calculated by subtracting supported ^{210}Pb (average of all ^{214}Bi counts from all samples within each of the cores) from the total ^{210}Pb activity at each level.

Percent organic matter was determined for twenty samples, including the samples that were ^{210}Pb dated using standard loss-on-ignition (LOI) methods (Dean, 1974). Briefly, 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.

Diatom Preparation and Enumeration

Slides for diatom analysis were prepared using standard techniques (Cumming et al. 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 water bath for approximately 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 approximately 8 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 valves 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).

Absolute abundance of diatoms was determined for all samples analyzed for diatoms using methods outlined in Battarbee & Kneen (1982). Absolute abundances were determined by spiking each of the diatom samples, prior to settling on coverslips, with a known concentration of microspheres. The microspheres were enumerated along with the diatoms and used to calculate estimates of # diatoms per gram dry weight. Total diatom concentration (#/g dry weight x 10^8) provides a means of assessing whether there were any changes in diatom production during the time period analyzed.

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 268 freshwater lakes from across British Columbia. This dataset includes lakes from several regions within British Columbia. 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 0.62, and the bootstrapped r^2 is 0.51. This model is superior to the earlier models developed by Reavie et al. (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 (Figs. 1E) were critically assessed to determine if they tracked the main direction of variation in the diatom species assemblages (Figs. 1D). If the diatom-based phosphorus reconstructions match the main direction of variation in the diatom assemblages in the core, then we can be fairly confident that the diatoms are tracking changes that are related to phosphorus, or correlated variables. 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., water depth, conductivity, turbulence, etc), or interactions between environmental variables, are likely responsible for the observed changes in diatom assemblages.

Determination of the Main Direction of Variation

The main direction of variation in the diatom assemblages in the Nukko Lake core was determined from the axis-1 scores from a principal components analysis (PCA) ordination using non-transformed species abundance data (Figs. 1D). A PCA was chosen to represent the main direction of variation of the diatom assemblages in these cores based on the small gradient length (< 1.5 standard deviation units) obtained in an initial detrended correspondence analysis (DCA) ordination.

Cluster Analysis

Cluster analysis provides a means of grouping those samples that are most similar to each other. The programs, TILIA and TGVIEW 2.02 (Grimm, unpublished), were used to provide a stratigraphic sequence (downcore) of the diatom assemblages and the cluster analyses (Fig. 2.). The cluster analyses were stratigraphical constrained in order to group the assemblages according to core depth (or core age) using square-rooted species data.

RESULTS AND DISCUSSION

^{210}Pb Profile, Sedimentation Rates and Organic Matter

The ^{210}Pb activity of the Nukko Lake core was very low (Fig. 1A). As a consequence it is extremely difficult to estimate dates for all sediment levels with any accuracy. Unsupported ^{210}Pb is only present in the uppermost 7 cm of the core after which, unsupported activity is difficult to differentiate from background (or in situ decay of ^{210}Pb). That said, we can confidently say that there is at least ~44 years of sediment represented by the uppermost 6-cm of the sediment core (two half-lifes of unsupported ^{210}Pb). This is supported by the relatively distinct ^{137}Cs profile which shows a peak at sediment depth of ~2.5 to 3 cm (Fig. 1B). This ^{137}Cs peak provides an estimate for 1963 as it is a consequence of the peak in atmospheric testing of nuclear weapons, and consequently fallout of isotopes such as ^{137}Cs. Thus, an estimated date of ~1960 AD can thus be given for the depth level of ~3-4 cm, and based on similar rates of sediment accumulation, an the year 1900 AD is likely reached by a depth of 8-9 cm. However, the c. 1900 boundary may be as low as ~14 cm. The large uncertainty around this estimate is because the changes in percent organic matter are large between ~14-cm to 8-cm depth (Fig. 1C). Typically such changes are associated with watershed disturbances, with resultant changes in sediment accumulation rates. Because of the low ^{210}Pb activities in this core and changes in organic matter (potentially indicating a mass deposition event between 12 and 8 cm depth), we are only able to estimate the c. 1900 boundary.

Diatom Assemblage Changes and Analyses

Approximately one-hundred and thirty taxa were documented in the core from Nukko Lake. However, most of these taxa are rare. Pre-1900 AD the assemblage was comprised primarily of small mesotrophic *Fragilaria* taxa (Fig. 2). Post-1900 the dominance of the small benthic taxa declines and increases in planktonic taxa occur.

Cluster analysis suggests two major periods of diatom assemblages in the recent history of the lake (Fig. 2). In Zone B, representing the time period prior to 1900 AD, the diatom assemblage is dominated by the benthic mesotrophic taxa, *Fragilaria pinnata*, *Fragilaria construens* and *Fragilaria brevistriata*. In Zone A2, there is a distinct change in the assemblage with increases in the more oligotrophic planktonic, *Cyclotella stelligera*, as well as smaller increases in mesotrophic and eutrophic planktonic taxa, *Tabellaria flocculosa*, *Asterionella formosa*, *Fragilaria crotonensis* and *Aulacoseira ambigua*. In Zone A1 (c. post 1960), *Cyclotella stelligera* continues to increase along with small increases in the eutrophic planktonic taxon, *Stephanodiscus parvus*. A distinct increase in chrysophytes relative to diatoms is also seen in the post 1900 sediments, with the largest increases occurring in the post-1960 sediments (Fig. 2).

Diatom-inferred total phosphorus (TP) estimates indicate mid-summer mesotrophic conditions that vary between 9 to 14 μgL^{-1} (Fig. 1E) since ~ 1900. Estimates of TP pre-1900 (Zone B) indicate more stable estimates of around ~14 μgL^{-1}. Post-1900 (Zone A), TP estimates indicate a gradual decline from 14 to 9 μgL^{-1}. This decline is being largely driven by the increase in the more oligotrophic planktonic, *Cyclotella stelligera.*

The correlation between the first main direction of variation in taxa (i.e., PCA axis-1 scores, Fig. 1D) and the log TP inferences (Fig. 1E) is very high ($r^2 = 0.86$) indicating that the changes seen in the diatom assemblages are consistent with the changes seen in the TP estimates. All dominant taxa, which are driving the reconstructions of TP, are well represented in our modern-day calibration set, thus providing evidence that the TP estimates are reliable.

DISCUSSION

The increase in *Cyclotella stelligera* may not be an indication of decreasing trophic conditions, but is more likely indicating an increasing degree of stratification within the lake (e.g., Harris et al. 2006 and references therein). Increased stratification, post 1900, is also indicated by the distinct increase in the scale to diatom ratio in Zone A2, which further increases in Zone A1, concurrent with the increases in *Cyclotella stelligera*. Scaled chrysophytes are exclusively planktonic and do well when a lake becomes stratified (in comparison to diatoms), as the scaled chrysophytes are flagellated and consequently have some control over their mobility in less turbulent environments. Increased lake stratification could have other important limnological consequences including increases in overall production and increases in green and blue-green algal populations. An overall increase in diatom concentrations is not apparent in the total diatom concentration (Fig. 2), but more mesotrophic and eutrophic planktonic diatoms also increase in abundance post 1900. Increases in other algal groups could be examined through pigment analysis of core sediments to see if they support this interpretation. The increased warming, especially since the mid 1970s is apparent in the instrumental records from the Prince George region (e.g. Laird et al. 2001).

SUMMARY

In summary, the diatom-inferred TP level of Nukko Lake indicates a relatively productive lake during the recent history, with mesotrophic estimates ranging between 9 to 14 μgL^{-1}. Estimates of TP indicate declining trophic status post-1900. However, this is largely being driven by the distinct increase in *Cyclotella stelligera*, which may indicate increased stratification. Increasing stratification is collaborated by the increased scale:diatom ratio concurrent with increasing abundance of *Cyclotella stelligera*, particularly post 1960. Smaller increases in more mesotrophic and eutrophic planktonic taxa post 1900, also indicates a change within the lake system sometime during the past 100 years.

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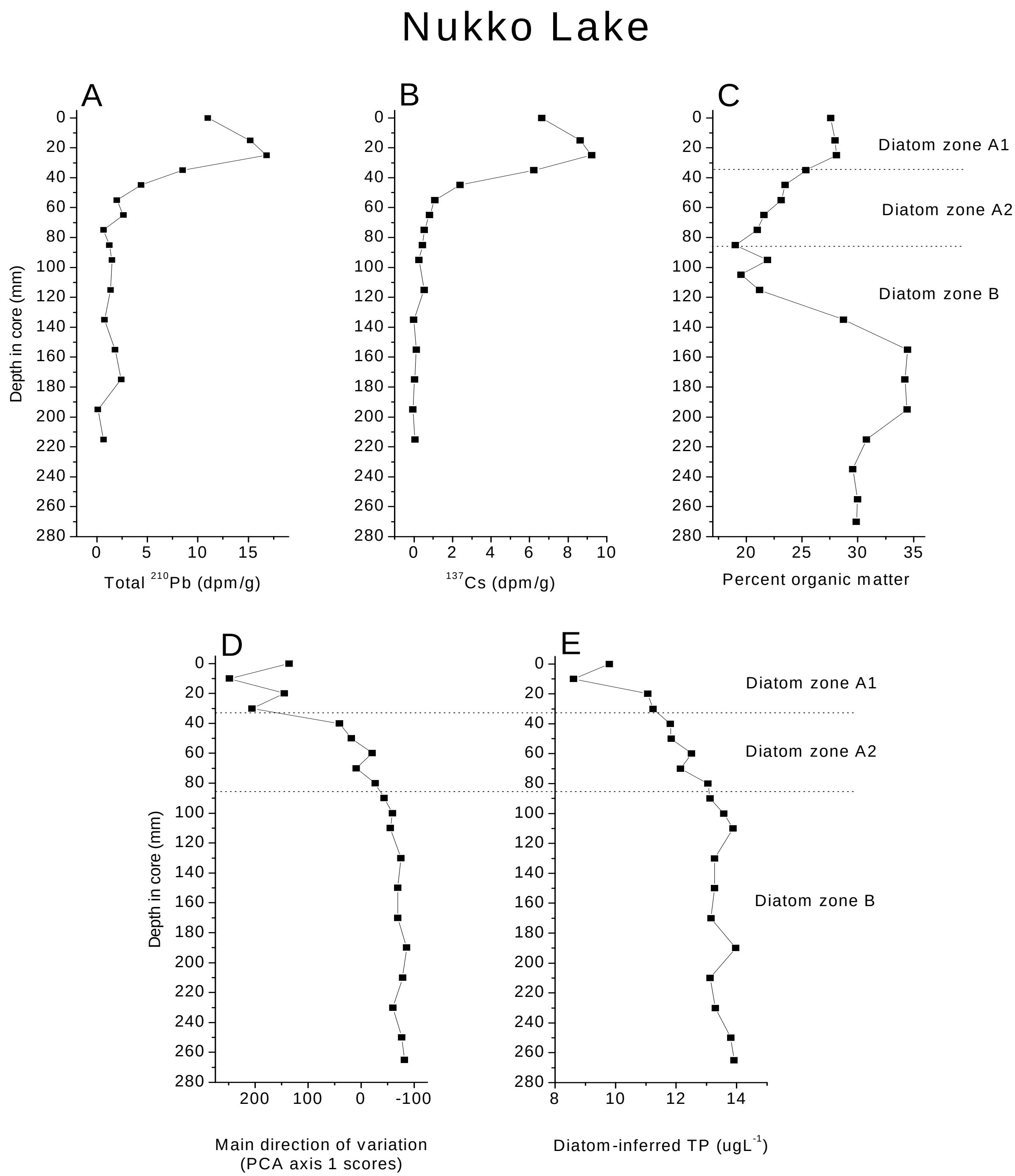

Figure 1. Summary diagram for Nukko Lake showing: A) total ^{210}Pb activity; B) the ^{137}Cs activity; C) the change in the percent of organic matter in the core; D) the main direction of variation in the diatom assemblage data; and E) diatom-based estimated of late-summer total phosphorus.

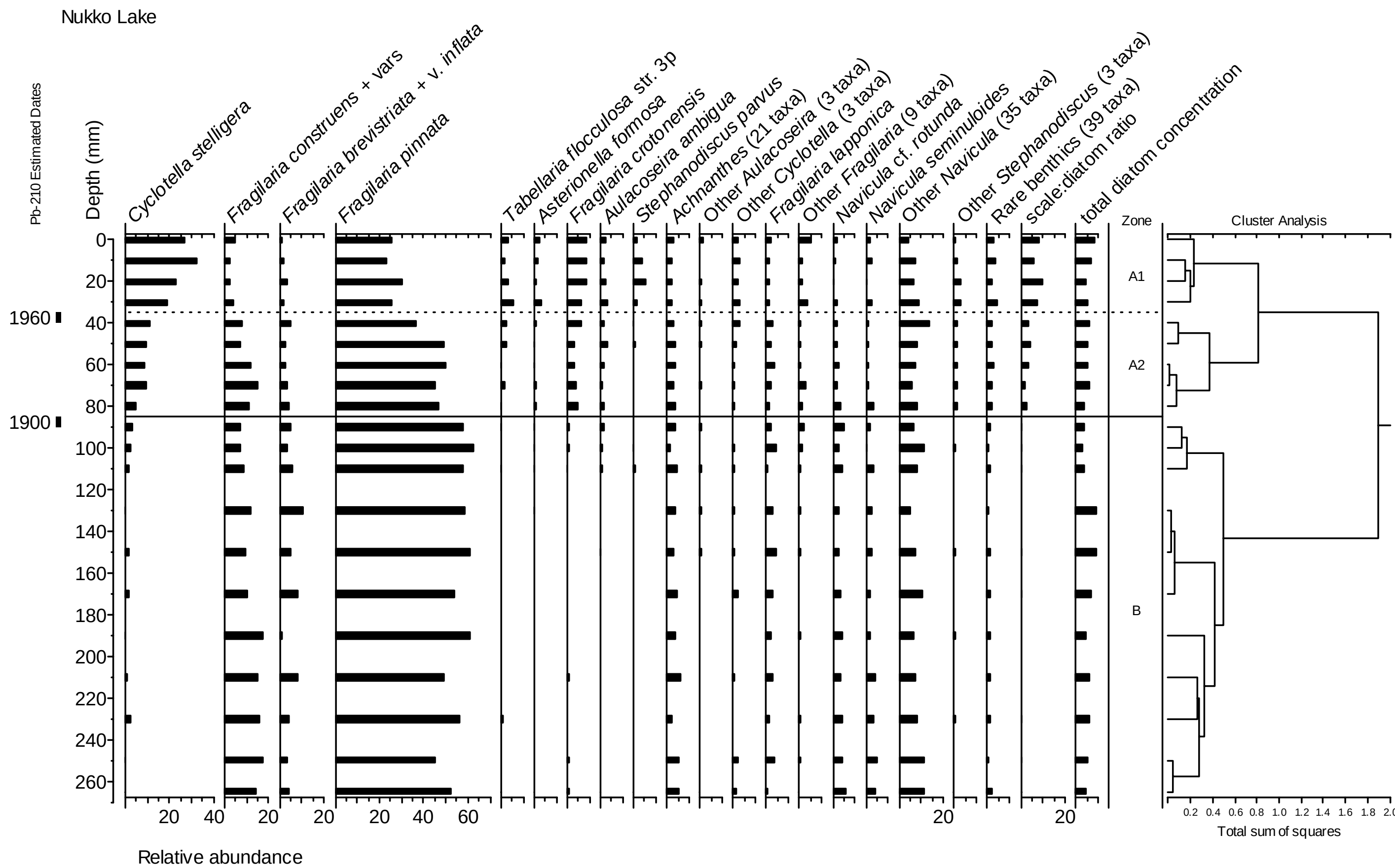

Figure 2. Stratigraphy of the most abundant diatom taxa found in the sediment core from Nukko Lake. The diatom taxa are arranged in order of increasing late-summer total phosphorus (TP) optima.