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Sediment core study of Loch Langavat, Isle of Harris
Final Report to Marine Harvest

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Executive Summary

1. This is the final report to Marine Harvest on a 'Sediment core study of Loch Langavat, Isle of Harris'. This project aims to assess changes in productivity in the loch since approximately 1850 AD using the diatom record.

2. A sediment core, 32 cm in length, was taken on 27th December 2003 from the southern part of the loch at location NG 04900 89070. The core was a very dark brown, homogenous organic mud throughout with no visible colour or textural changes.

3. Spheroidal carbonaceous particle (SCP) analysis of sixteen samples from the core produced a concentration profile displaying all the characteristic features seen in lake sediment cores throughout Europe. The SCP derived chronology indicates a reasonably consistent and low sediment accumulation rate over the last 150 years of 1.16 – 1.67 mm yr^{-1}. Extrapolation of this chronology would suggest that 1850 occurs at a depth of 23 – 27cm. This depth is just below the depth of first SCP presence confirming that the concentration profile is slightly truncated as a result of low levels of deposition in the nineteenth century. A suitable depth for a reference sample would therefore be below 27 cm, and the 30 cm sample was selected.

4. Six samples, representing the dates ~1850, ~1950, 1990, 1995, 1999 and 2003, were analysed for diatoms. Diatom preservation was good throughout and a total of 118 taxa were observed. The assemblages shift from dominance by *Cyclotella comensis* types and *Cyclotella kuetzingiana* var. *planetophora*, typically found in oligotrophic waters, to *Cyclotella pseudostelligera* and *Asterionella formosa*, taxa associated with mesotrophic conditions. The species shifts indicate enrichment of the loch in the last decade. Similar diatom shifts have been observed in other formerly oligotrophic Scottish lochs impacted by enrichment.

5. Diatom transfer functions that reconstructed total phosphorus (TP) concentrations were used to evaluate eutrophication. The diatom-inferred TP (DI-TP) reconstruction indicated that TP concentrations were ~6 µg l^{-1} for the samples dated to ~1850, 1950 and 1990. Inferred concentrations then began to rise with a DI-TP value of 9 µg l^{-1} for the sample dated to ~1995 and a further increase to values of 12-13 µg l^{-1} for the 1999 and 2003 samples. The DI-TP values for the recent samples compared well with the current annual mean TP of the loch measured as 12 µg l^{-1} in 2002 and 9 µg l^{-1} in 2003.

6. The palaeoecological data provide evidence that the loch has changed ecologically in response to recent enrichment and is no longer in a reference state. Given the low resolution of the present study, the exact date of onset of enrichment cannot be determined but the major shifts have occurred post-1985 and are therefore coincident with the arrival of the fish farm. It is uncertain whether the loch is now in a new stable state or if further enrichment may take place.

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1. INTRODUCTION

1.1 Study rationale

The primary objective of this project is to use palaeoecological techniques, principally diatom analysis, to assess changes in the trophic status of Loch Langavat, Isle of Harris, over approximately the last 150 years. A fish farm was established on the loch in 1985 and Marine Harvest (the fish farm operators) have recently applied to the Scottish Environment Protection Agency (SEPA) to increase production. SEPA wish to assess the trophic status, as determined by total phosphorus (TP) concentrations, of the loch prior to the installation of the fish farm in order to assess the loch's original status or 'reference condition', according to European Council Water Framework Directive terminology (European Union, 2000).

1.2 Objectives

The objectives of the study were to:

1. Collect a sediment core from the loch.
2. Provide a chronology of the lake sediments using spheroidal carbonaceous particles (SCPs).
3. Infer past total phosphorus (TP) conditions from analysis of diatom assemblages in the core and application of diatom-phosphorus transfer functions. Primary interest was in establishing TP for:
    a. ~1850 to represent reference condition,
    b. ~1950 to represent pre-fish farm development,
    c. two to three dates following the establishment of the fish farm,
    d. the surface sample to represent current condition.

1.3 Study site

Loch Langavat is a freshwater loch situated near Finsbay in the southern part of the Isle of Harris, Outer Hebrides (National Grid Reference NG 045 895). The loch has a surface area of 1.41 km^2, a mean depth of 5.31 m and a volume of 7.5 x 10^6 m^3 of water. A fish farm was established on the loch in 1985 and continues to operate to the present day. A bi-annual sampling programme was initiated in 1988 to assess long term water quality fluctuations (Institute of Aquaculture, 2003). This involves the measurement of a range of parameters including pH, TP, secchi depth and chlorophyll a. These surveys show that the loch is circumneutral to slightly acid (pH ~6.3). The mean water column TP concentration in June 2003 was 9 $\mu g\ l^{-1}$ and the mean chlorophyll a concentration was 2.3 $\mu g\ l^{-1}$, placing the loch in the mesotrophic category. The water chemistry records indicate that mean TP concentrations were higher in the late 1980s with values of ~20 μg TP l^{-1} but have fluctuated between ~10-15 μg TP l^{-1} since that time (Institute of Aquaculture, 2003).

2. METHODS

2.1 Coring and lithostratigraphic analyses

A Glew gravity core (coded LGVT1), 32 cm in length, was taken on 27th December 2003 from the southern part of the loch at location NG 04900 89070. The core was taken from a deep basin of open water (18 m water depth) in order to represent, as best as possible, the whole-loch situation and was not taken immediately adjacent to either of the fish rearing cage-units. The core was extruded at 0.5 cm intervals and the main characteristics of the sediment and any stratigraphic changes were noted. The percentage dry weight (%DW) which gives a measure of the water content of the sediment, and percentage loss on ignition (%LOI) which gives a measure of the organic matter content, were determined by standard techniques (Dean, 1974). These measures allow changes in sediment composition to be identified.

2.2 Spheroidal carbonaceous particle analyses (SCPs)

Sediment samples from LGVT1 were analysed for spheroidal carbonaceous particles (SCPs) following the method described in Rose (1994) in order to derive a chronology for the core. Dried sediment was subjected to sequential chemical attack by mineral acids to remove unwanted fractions leaving carbonaceous material and a few persistent minerals. SCPs are composed mostly of elemental carbon and are chemically robust. The use of concentrated nitric acid (to remove organic material), hydrofluoric acid (siliceous material) and hydrochloric acid (carbonates and bicarbonates) therefore does them no damage. A known fraction of the resulting suspension was evaporated onto a coverslip and mounted onto a microscope slide. The number of SCP on the coverslip were counted using a light microscope at x400 magnification and the sediment concentration calculated in units of 'number of particles per gram dry mass of sediment' (gDM^{-1}). The detection limit for the technique is ~100 gDM^{-1} and concentrations have an accuracy of ~± 45 gDM^{-1}.

2.3 Diatom analyses

In the absence of long-term historical water chemistry data, the sediment accumulated in lakes can provide a record of past events and past chemical conditions (e.g. Smol, 1992). Diatoms (*Bacillariophyceae*) are unicellular, siliceous algae and their valves (siliceous component of the cell wall bearing the taxonomic features) are generally well preserved in most lake sediments. Diatoms are sensitive to water quality changes and are, therefore, good indicators of past lake conditions such as lake pH, nutrient concentrations and salinity. The diatom record is a potentially useful tool for assessing water quality and defining lake reference conditions, both chemical and ecological.

For the UK, it is generally agreed that approximately 1850 AD is a suitable date against which to assess impacts for lakes as this represents a period prior to major industrialisation and agricultural intensification (Battarbee, 1999; Fozzard *et al.*, 1999). In this study, therefore, we take ~1850 AD to represent the reference condition of the loch. Six sub-samples from the core, selected to cover the period of interest (i.e. 1850 to the present day), were prepared and analysed for diatoms using standard techniques (Battarbee *et al.*, 2001). At least 300 valves were counted from each sample using a Leitz research microscope with a 100x oil immersion objective (magnification 1000x) and phase contrast. A further three slides from intermediate levels were scanned but not counted in order to provide additional data on the point of change in the core. Principal floras used in identification were Krammer & Lange-Bertalot (1986, 1988, 1991a, b) although other taxonomic floras and references were employed as necessary. Slides are archived at the ECRC. All diatom data are expressed as percentage relative abundance (% relative abundance) and plots were produced in the software package C^2 (Juggins, 2003). A simple measure of floristic diversity for each sample was calculated as the number of taxa divided by the total valve count.

2.4 Diatom transfer functions

In recent years, the technique of weighted averaging (WA) regression and calibration, developed by ter Braak (e.g. ter Braak & van Dam, 1989), has become a standard technique in palaeolimnology for reconstructing past environmental variables. A predictive equation known as a transfer function is generated that enables the inference of a selected environmental variable from fossil diatom assemblages, based on the relationship between modern surface-sediment diatom assemblages and contemporary environmental data for a large training (or calibration) set of lakes. This approach has been successfully employed to quantitatively infer lake total phosphorus (TP) concentrations (Hall & Smol, 1999), whereby modern diatom TP optima and tolerances are calculated for each taxon based on their distribution in the training set, and then past TP concentrations are derived from the weighted average of the optima of all diatoms present in a given fossil sample. The methodology and the advantages of WA over other methods of regression and calibration are well documented (e.g. ter Braak & van Dam, 1989).

The reconstruction of diatom-inferred total phosphorus (DI-TP) for Loch Langavat was produced using a newly developed, unpublished training set of 56 relatively large, deep lakes (> 10 m maximum depth) from Scotland, Northern Ireland, Cumbria, southern Norway and central Europe, with annual mean TP concentrations ranging from 1-73 µg TP l^{-1}, and a median value for the dataset of 22 µg TP l^{-1}. The training set contains 139 diatom taxa. The best model was generated with simple WA and inverse deshrinking.

The errors of the models are described by the root mean square error (RMSE) which essentially summarises the difference between the measured values for the training set of lakes and the diatom inferred values generated by the model. These are calculated based on the original training set (the apparent RMSE) and more realistically on a cross-validated test set (the RMSE of prediction or RMSEP). The lower the error, the better the model performs. The model performs well and has relatively low errors of prediction with an apparent RMSE and an RMSEP of 0.20 and 0.25 $\log_{10}$ µg TP l^{-1}, respectively.

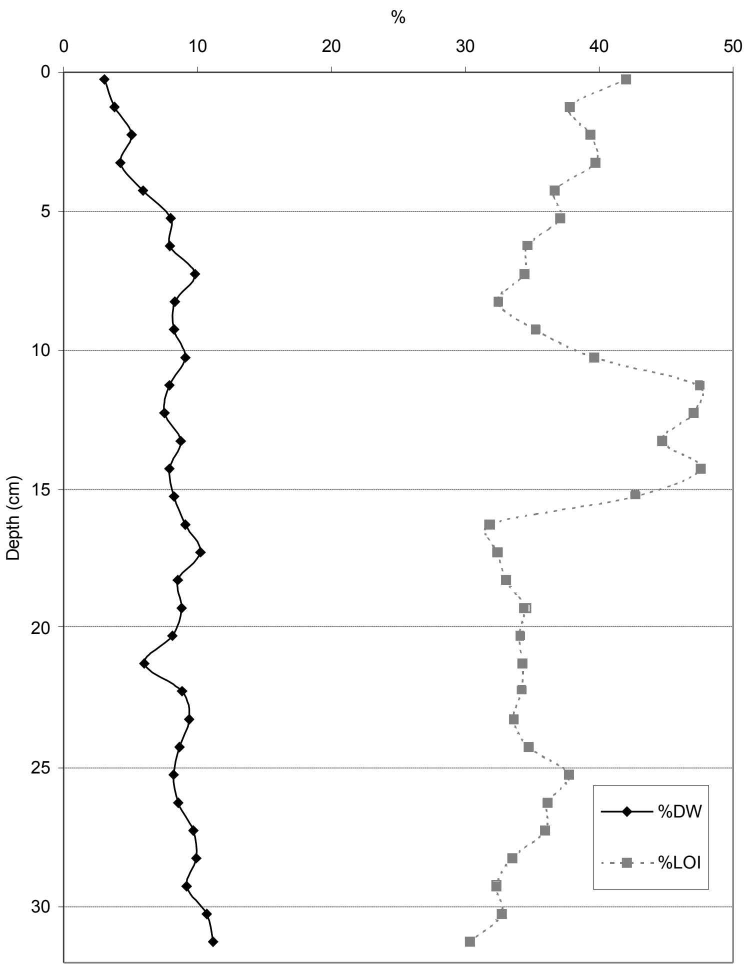
The model was applied following taxonomic harmonisation between the training set and core species data. The reconstructions were implemented using C^2 (Juggins, 2003). The TP data used in the models were $\log_{10}$-transformed annual mean concentrations (µg TP l^{-1}) as model performance is improved when the data are logged. However, inferred values have been transformed back to µg TP l^{-1} for the presentation of the results and for the purposes of discussion.

3. RESULTS

3.1 Core description

The core was a very dark brown, homogenous organic mud throughout with no visible colour or textural changes. All matter was well humified with a just a small number of plant remains present in the upper core. The dry weight was low throughout the core with values ranging from ~3 to 10% (Figure 1), reflecting the high water content of the sediment. Organic matter was relatively high with values of ~30-40% in the lowermost section from 15 to 32 cm and in the uppermost section from 0-10 cm. Organic matter content was slightly higher in the section from 10-15 cm with values > 45%.

Figure 1 Dry weight and organic matter profiles for Loch Langavat core LGVT1



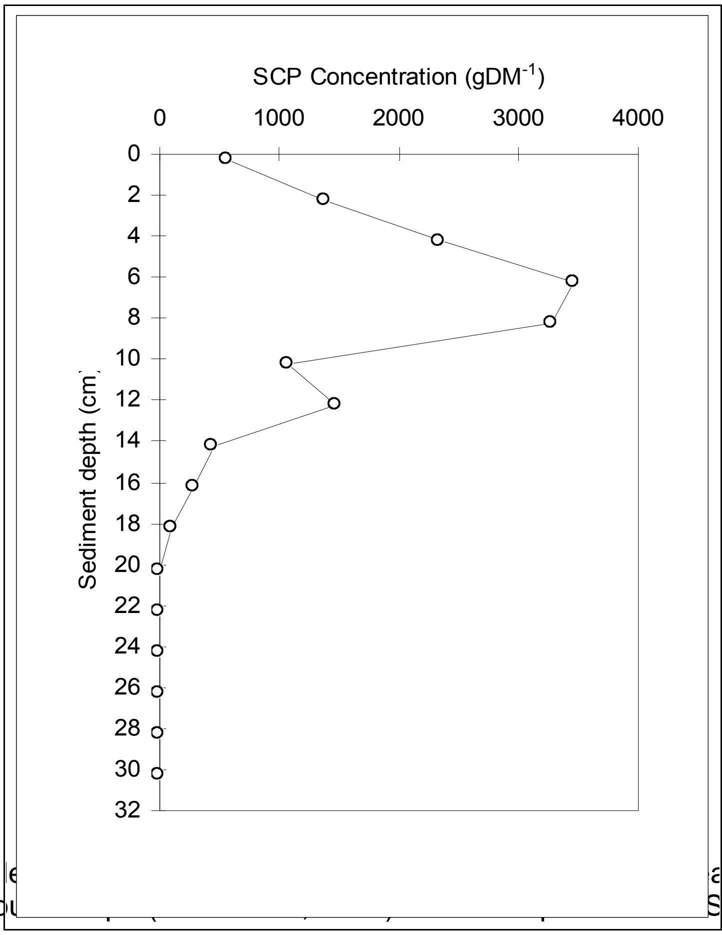
3.2 Spheroidal carbonaceous particles (SCPs)

Sixteen samples were analysed for spheroidal carbonaceous particles (SCPs) and the results are presented in Table 1 and the SCP concentration profile is shown in Figure 2.

Table 1 SCP concentrations with confidence limits

Sediment depth (cm)	SCP concentration (gDM^{-1})	90% Confidence limits (gDM^{-1})
0 – 0.5	566	959 – 174
2 – 2.5	1386	2170 – 602
4 – 4.5	2345	3373 – 1317
6 – 6.5	3454	4734 – 2175
8 – 8.5	3282	4252 – 2312
10 – 10.5	1078	1688 – 468
12 – 12.5	1475	2310 – 640
14 – 14.5	442	874 – 9
16 – 16.5	298	505 – 91
18 – 18.5	107	212 – 2
20 – 20.5	0	0 – 0
22 – 22.5	0	0 – 0
24 – 24.5	0	0 – 0
26 – 26.5	0	0 – 0
28 – 28.5	0	0 – 0
30 – 30.5	0	0 – 0

Figure 2 SCP concentration profile of Loch Langavat core LGVT1



The SCP profil ... atures seen in lake sediment cores througho ... SCPs occurs at 18 – 18.5 cm and concentrations increase steadily until ~10 cm when concentrations increase rapidly to a peak of almost 3,500 gDM^{-1} at 6 – 6.5 cm. From this point, SCP concentrations decline markedly to the sediment surface.

The SCP record in European lake sediments has been found to be so consistent and reliable (there are no problems of re-mobilisation or dissolution etc.) that one of the main uses of the SCP record has been for dating purposes (e.g. Rose *et al.*, 1995). In a given region, once a reliable SCP chronology has been established (using independent dating such as varve counting or ^{210}Pb dating etc.) then the SCP profile can be used with confidence to ascribe dates to the last 150 years of the sediment record. Traditionally, dates are attributed to the start of the record, the rapid increase in SCP concentration and the SCP concentration peak. Although there are regional variations, in Scotland the date of the start of the SCP record is usually given as the mid-nineteenth century as a result of developments in the Industrial Revolution, whilst the start of the rapid increase in SCP concentration is usually ascribed to ~1950 due to the boom in electricity generation after the Second World War. Usually the most replicable and identifiable feature within a region is the peak in SCP concentration. It is also the feature which is most likely to vary between one region and another as the “post-peak” decrease is due to many factors such as implementation of air quality legislation, introduction of particle arresting equipment and trends in industrial output, fuel use and economic development. In addition to these factors, the situation may be further complicated by the trans-boundary nature of the depositing particles. For example, most lakes receive deposition from the emissions of more than one country and the combination of national air quality legislation may result in a unique depositional regime for the region. However, in Scotland, the situation is simpler as most deposition is from the UK and the date for the peak is usually ~1978. Although slightly restricted by the number of samples analysed, the SCP peak for LGVT 1, and hence 1978, can be reasonably accurately allocated to ~6.5 cm.

For Loch Langavat the situation is slightly complicated towards the base of the core due to its location in one of the cleanest areas of the UK. Although a sensitive technique, SCP analysis, like any other analytical procedure is limited by the limit of detection. In recent sediments, or in areas where deposition is significant this is not a problem, but at Loch Langavat, the SCP profile appears truncated at the base of the core and this is probably due to low deposition in the nineteenth century.

More recently, the technique of dating sediment cores using SCPs has been developed (Rose & Appleby, in prep) such that dates are ascribed on the basis of cumulative percentage inventories calibrated using a number of independently dated profiles from across a number of defined regions in the UK. North Scotland forms one of these regions and the inventory dates for this region are based on 24 independently dated sediment cores. Being based on inventory data these profiles are not susceptible to many of the processes which may affect SCP concentrations (e.g. in-wash events) and hence the technique is more robust than ‘traditional’ SCP dating which uses concentration data only. The inventory technique uses the SCP peak depth as 100% and all other percentiles are calculated relative to it. The advantages of this approach are that all future cores can have dates allocated to them and that dates can be allocated to each 10-percentile resulting in 11 dates for each core rather than the previous three. The disadvantage is that only dates between 1850 and the peak date (in Scotland, 1978) can be allocated to a core.

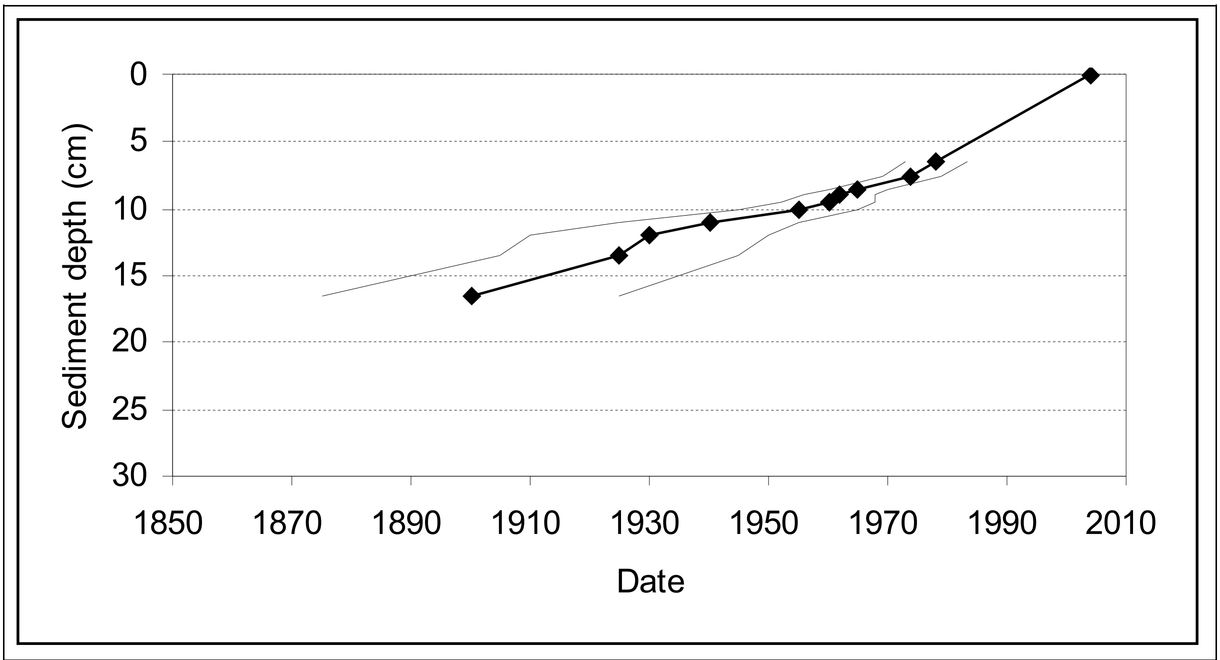
For Loch Langavat, although the truncated SCP concentration profile results in some uncertainty in the allocation of the earliest date (i.e. the start of the record at ~1850), as these early concentrations must be very low, the resulting inventories only alter the depth of the SCP inventory 10-percentile by a small amount. We can therefore estimate that the 10-percentile (allocated 1900 25) falls between 15.5 cm and 17 cm depth in this sediment core. Depths can be allocated to each of the other 10-percentiles resulting in the chronology shown in Table 2 and Figure 3. Errors given in this table are based on the variability between the 24 independently dated sediment cores from the region, and the errors from the original radiometric dating calibration.

Table 2 Dates and sediment depths for LGVT1 based on SCP analysis

Sediment depth (cm)	Ascribed date	

16.5	1900	25
13.5	1925	20
12	1930	20
11	1940	15
10	1955	15
9.5	1960	10
9	1962	6
8.5	1965	5
7.5	1974	5
6.5	1978	5
0 (Sediment surface)	2003 (Coring date)	0

Figure 3 SCP-derived chronology for Loch Langavat core LGVT1



The SCP derived chronology suggests a reasonably consistent and low sediment accumulation rate over the last 100 to 150 years. Extrapolation of this chronology would suggest that 1850 occurs at a depth of 23 – 27cm. This depth is just below the depth of first SCP presence confirming that the concentration profile is slightly truncated as a result of low levels of deposition.

In summary:

- The SCP concentration profile for Loch Langavat core LGVT 1 shows low levels of atmospherically deposited contamination and it is likely that the profile is truncated as a result of concentrations below the limits of detection in the nineteenth century.

- This truncation means that the start of the record cannot be accurately determined. However, using the cumulative inventory approach, the remainder of the dates can be allocated and a reasonable estimate of the 10-percentile (1900 25) date can be made.

- These calculated dates suggest a reasonably steady and low sediment accumulation rate and that the mean accumulation over the last 150 years is in the region of 1.16 – 1.67 mm yr^{-1}

- Extrapolation of the chronology suggests that 1850 is between 23 and 27cm. A suitable depth for a reference sample would therefore be below 27cm.

3.3 Diatoms

Six samples were analysed for diatoms in Loch Langavat core LGVT1 (Table 3). Diatom preservation was good throughout the core and a total of 118 taxa were observed (Appendix 1). All six samples were relatively diverse with between 40 and 60 taxa observed per sample although diversity decreased up the core (Table 3) owing to the strong co-dominance of two planktonic taxa, *Asterionella formosa* and *Cyclotella pseudostelligera*. Summary diatom results for each sample are given in Appendix 2.

Table 3 Summary of samples analysed for diatoms in Loch Langavat core LGVT1

Depth (cm)	Total valve count	No. diatom taxa	Floristic diversity	Approximate sample date (AD)
0-0.5	400	41	0.10	2003
1-1.5	425	46	0.11	1999
2-2.5	402	55	0.14	1995
4-4.5	351	60	0.17	1990
10-10.5	361	57	0.16	1950
30-30.5	368	58	0.16	1850

The summary diatom diagram (Figure 4), showing only the 16 taxa present with a maximum abundance of > 2%, illustrates marked shifts in the diatom assemblages. The two samples representing 1850 and 1950 are dominated by *Cyclotella comensis* types and *Cyclotella kuetzingiana* var. p*lanetophora*, planktonic taxa associated with oligotrophic waters, and also a number of non-planktonic species notably *Brachysira neoexilis*, *Achnanthes minutissima* and *Fragilaria virescens* var. *exigua.* The samples representing the period 1990 to the present day are comprised of many of the taxa seen in the earlier samples but there is a major shift in species composition with a marked increase in *Asterionella formosa* in the sample dated to 1990 (from <1% to 13%) and a decline in the relative abundance of the *Cyclotella comensis* taxa (from 32% to 5%). Further changes are seen in the upper core with a steady increase in *Cyclotella pseudostelligera* (to a maximum of 43% in the surface sample) and continued expansion of *Asterionella formosa* (to a maximum of 31%), both taxa typically associated with mesotrophic waters. Scanning of slides from intermediate samples, 8-8.5 cm (~1965), 15-15.5 cm (~1915) and 25-25.5 cm (~1850), showed that the assemblages were very similar to those of the 10-10.5 cm and 30-30.5 cm samples (i.e. dominated by *Cyclotella comensis* types and *Cyclotella kuetzingiana* var. *planetophora*).

3.4 Diatom transfer functions

The major taxa in the sediment core were well represented in the training set with greater than 80% of the fossil assemblage being present in the training set for all samples. The diatom-inferred total phosphorus (DI-TP) reconstruction (Figure 5) produced values of ~6 μg l^{-1} for the samples dated to ~1850, 1950 and 1990. Inferred concentrations then began to rise with a DI-TP value of 9 μg l^{-1} for the sample dated to ~1995 and a further increase to values of 12-13 μg l^{-1} for the 1999 and 2003 samples. The DI-TP values for these recent samples compare well with the current annual mean TP of the loch measured as 12 μg l^{-1} in 2002 and 9 μg l^{-1} in 2003 (Institute of Aquaculture, 2003).

Figure 4 Summary diatom diagram of Loch Langavat core LGVT1 **(only taxa occurring at >2% maximum abundance are shown)**

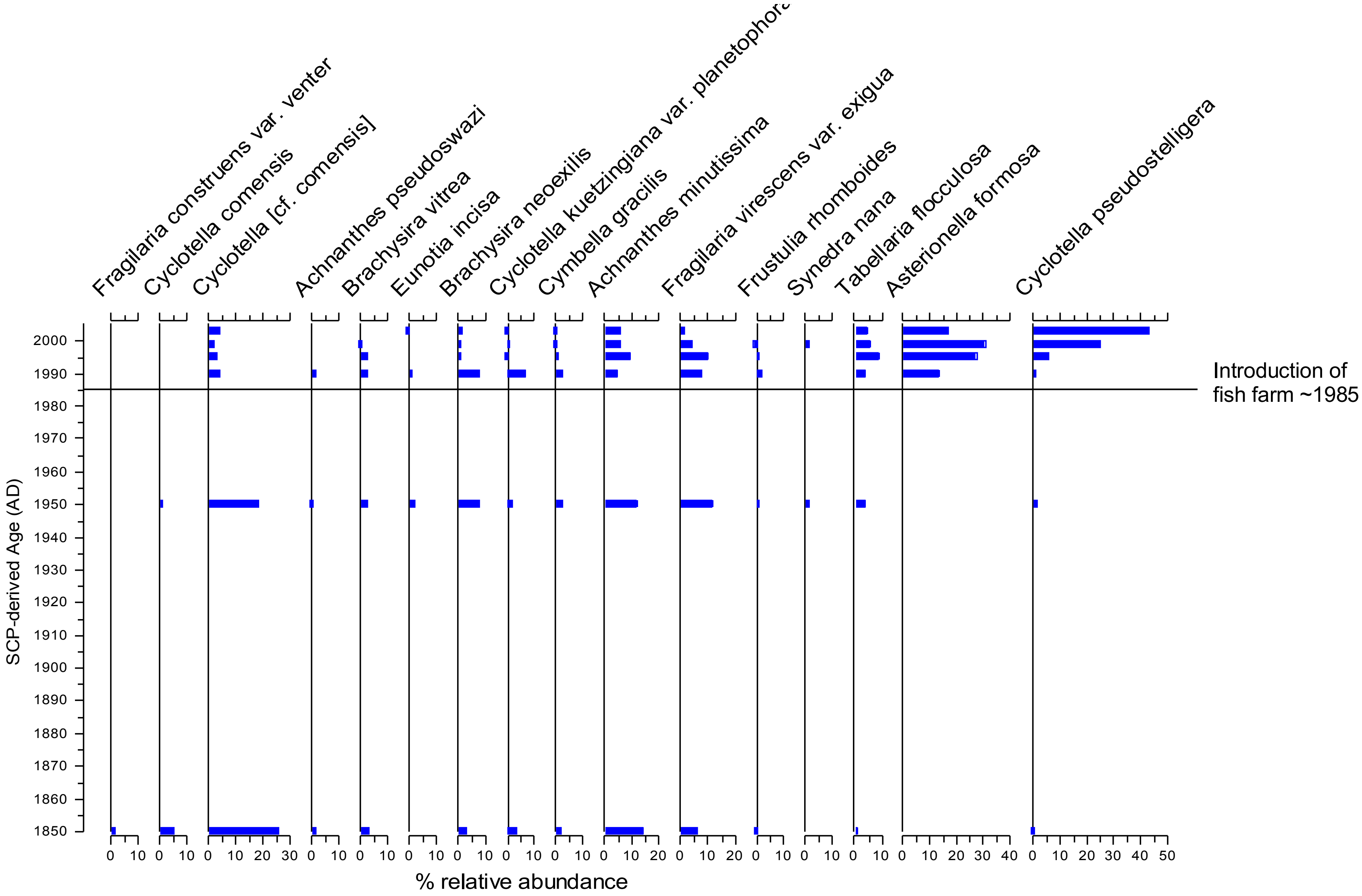
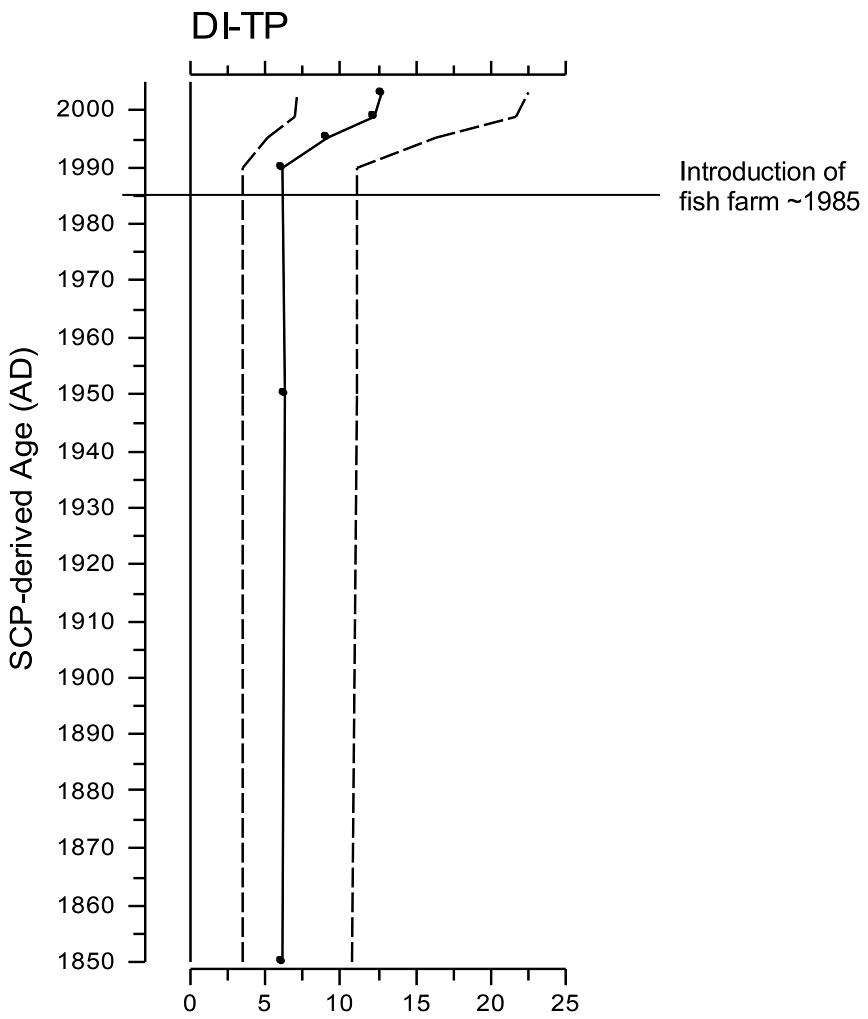


Figure 5 Diatom-inferred total phosphorus (DI-TP µg l^{-1}) reconstruction for Loch Langavat core LGVT1 **(Dashed lines indicate the RMSEP)**



4. DISCUSSION

The diatom record of Loch Langavat exhibits major changes throughout the period represented by the sediment core, which dates from ~1850 AD as shown by SCP analyses. The assemblages shift from dominance by *Cyclotella comensis* types and *Cyclotella kuetzingiana* var. *planetophora*, typically found in oligotrophic waters, to *Cyclotella pseudostelligera* and *Asterionella formosa*, taxa associated with mesotrophic conditions. Based on knowledge of the ecology of these taxa, the species shifts indicate enrichment of the loch in the last decade. This is further illustrated by application of the diatom-phosphorus transfer function which indicates that TP concentrations in the loch were ~6 µg l^{-1} until around 1990 and doubled to ~12-13 µg l^{-1} by 1999. The taxa which dominate the lower samples have relatively low DI-TP optima in the model, e.g. *Cyclotella kuetzingiana* (6.5 µg l^{-1}), *Cyclotella comensis* (8.5 µg l^{-1}) and *Achnanthes minutissima* (11 µg l^{-1}) whereas those in the upper samples have higher optima, e.g. *Asterionella formosa* (15 µg l^{-1}) and *Cyclotella pseudostelligera* (17 µg l^{-1}). The DI-TP values for the recent samples compare well with the current annual mean TP of the loch suggesting that the reconstructed values should be reliable.

Similar palaeoecological studies of 26 Scottish loch basins have shown that deep lochs are typically characterised by oligotrophic, acidophilous-circumneutral taxa, particularly *Cyclotella kuetzingiana*, *Cyclotella comensis*, *Tabellaria flocculosa, Achnanthes minutissima* and *Brachysira vitrea*, in their reference samples (Bennion *et al*., 2004), i.e. the same taxa as those found in the lower samples of the Loch Langavat core. Where sites have few sources of nutrients and have not been impacted by eutrophication, the same assemblages were present in the surface samples of the cores (e.g. at Lochs Eck, Lubnaig, Maree, Rannoch and Shiel). However, at a number of deep lochs (e.g. Lochs Awe, Doon, Earn, Lomond and Lake of Menteith), Bennion *et al*. (2004) observed a shift from the *Cyclotella*-*Achnanthes* assemblage to a planktonic assemblage typical of mesotrophic waters. *Asterionella formosa*, one of the taxa which appeared in the upper samples of the Loch Langavat core, was one of the species commonly seen in the impacted lochs. In contrast to the minimally impacted lochs, the sources of nutrients to these enriched waters are many. For example, Lochs Lomond, Awe and Earn receive diffuse agricultural and forestry inputs, and sewage effluent from villages and hotels. In the latter two cases, there are additional sources of nutrients from fish cages.

As seen in Loch Langavat, some of the large, formerly oligotrophic waters in the Bennion *et al*. (2004) study exhibited marked increases in DI-TP following a period of relatively stable conditions. The changes in the diatom assemblages of some of these lochs were sufficient to result in two to three-fold increases in DI-TP concentrations, and at Loch Langavat the model suggests a two-fold increase from ~6 to ~12 µg l^{-1}.

The diatom data provide evidence that whilst the loch remains on the border of oligotrophic to mesotrophic (according to the water quality survey data), it has changed ecologically in response to recent enrichment and is no longer in a reference state. The data indicate that an ecologically important threshold has been crossed. Given the low resolution of the present study, the exact date of onset of enrichment cannot be determined but the major shifts have occurred post-1985 and are therefore coincident with the arrival of the fish farm. Oligotrophic lochs such as Loch Langavat appear to be highly sensitive to any pressure placed upon them, most likely because of their extremely nutrient-poor, natural condition. The establishment of the fish farm in the mid-1980s would not surprisingly, therefore, result in a shift in trophic status of the loch. The resolution of the palaeoecological data does not allow us to assess whether the loch is now in a new stable state or whether further enrichment may take place.

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Appendix 1 Full list of diatom taxa found in Loch Langavat core LGVT1 with diatom codes and authorities (Total number of taxa: 118)

AC002A	Achnanthes linearis (W. Sm.) Grun. in Cleve & Grun. 1880
AC004A	Achnanthes pseudoswazi J.R. Carter 1963
AC013A	Achnanthes minutissima minutissima Kutz. 1833
AC014A	Achnanthes austriaca austriaca Hust. 1922
AC019A	Achnanthes nodosa A. Cleve-Euler 1900
AC022A	Achnanthes marginulata Grun. in Cleve & Grun. 1880
AC025A	Achnanthes flexella (Kutz.) Brun 1880
AC035A	Achnanthes pusilla pusilla Grun. in Cleve & Grun. 1880
AC037A	Achnanthes biasolettiana Grun. in Cleve & Grun. 1880
AC044A	Achnanthes levanderi Hust. 1933
AC060A	Achnanthes curtissima J.R. Carter 1963
AC082A	Achnanthes kriegeri Krasske 1943
AC083A	Achnanthes laevis Ostr. 1910
AC105A	Achnanthes petersenii Hust. 1937
AC134A	Achnanthes helvetica (Hustedt) Lange-Bertalot in LB & K 1989
AC136A	Achnanthes subatomoides (Hust.) Lange-Bertalot & Archibald in Krammer & Lange-Bertalot 1985
AC153A	Achnanthes impexa Lange-Bertalot 1989
AC161A	Achnanthes ventralis (Krasske) Lange-Bertalot 1989
AC182A	Achnanthes rosenstockii Lange-Bertalot 1989
AC9999	Achnanthes sp.
AS001A	Asterionella formosa formosa Hassall 1850
AU004B	Aulacoseira lirata lacustris (Grun. in Van Heurck) R. Ross in Hartley 1986
AU032A	Aulacoseira lacustris Krammer 1990
BR001A	Brachysira vitrea (Grun.) R. Ross in Hartley 1986
BR006A	Brachysira brebissonii brebissonii R. Ross in Hartley 1986
BR010A	Brachysira neoexilis Lange-Bertalot 1994
BR011A	Brachysira procera L-B & Moser 1994
CM004A	Cymbella microcephala microcephala Grun. in Van Heurck 1880
CM010A	Cymbella perpusilla A. Cleve 1895
CM015A	Cymbella cesatii cesatii (Rabenh.) Grun. in A. Schmidt 1881
CM018A	Cymbella gracilis (Rabenh.) Cleve 1894
CM020A	Cymbella gaeumannii Meister 1934
CM031A	Cymbella minuta minuta Hilse ex Rabenh. 1862
CM049A	Cymbella failaisensis (Grun.) Krammer & Lange-Bertalot 1985
CM052A	Cymbella descripta (Hust.) Krammer & Lange-Bertalot 1985
CM085A	Cymbella lapponica Grun. ex Cleve 1894
CM103A	Cymbella silesiaca Bleisch ex Rabenh. 1864
CO001A	Cocconeis placentula placentula Ehrenb. 1838
CY002A	Cyclotella pseudostelligera Hust. 1939
CY006B	Cyclotella kuetzingiana planetophora Fricke in A. Schmidt 1900
CY007A	Cyclotella glomerata Bachm. 1911
CY009A	Cyclotella ocellata Pant. 1902
CY010A	Cyclotella comensis Grun. in Van Heurck 1882
CY019A	Cyclotella radiosa (Grunow) Lemmerman 1900
CY028B	Cyclotella distinguenda unipunctata (Hustedt) Hakansson & Carter 1990
CY9985	Cyclotella [cf. radiosa] Massif Central (PR) 1997
CY9987	Cyclotella [cf. comensis] Massif Central (PR) 1997
CY9999	Cyclotella sp.
DE001A	Denticula tenuis tenuis Kutz. 1844
EU002B	Eunotia pectinalis minor (Kutz.) Rabenh. 1864
EU007A	Eunotia bidentula W. Sm. 1856
EU011A	Eunotia rhomboidea Hust. 1950
EU016A	Eunotia diodon Ehrenb. 1837
EU017A	Eunotia flexuosa flexuosa Kutz. 1849
EU043A	Eunotia elegans Ostr. 1910
EU047A	Eunotia incisa W. Sm. ex Greg. 1854
EU048A	Eunotia naegelii Migula 1907
EU070A	Eunotia bilunaris (Ehrenb.) F.W. Mills 1934

EU070B	Eunotia bilunaris mucophila LB & Norpel 1991
EU105A	Eunotia subarcuoides Alles, Norpel, Lange-Bertalot 1991
EU106A	Eunotia rhynchocephela Hustedt 1936
EU107A	Eunotia implicata Norpel, Lange-Bertalot & Alles 1991
EU110A	Eunotia minor (Kutz) Grunow in Van Heurck 1881
FR002A	Fragilaria construens construens (Ehrenb.) Grun. 1862
FR002C	Fragilaria construens venter (Ehrenb.) Grun. in Van Heurck 1881
FR005D	Fragilaria virescens exigua Grun. in Van Heurck 1881
FR009H	Fragilaria capucina gracilis (Oestrup) Hustedt 1950
FR009J	Fragilaria capucina perminuta (Grun.) L-B. 1991
FU002A	Frustulia rhomboides rhomboides (Ehrenb.) De Toni 1891
FU002B	Frustulia rhomboides saxonica (Rabenh.) De Toni 1891
FU002E	Frustulia rhomboides saxonica undulata Hust.
GO003A	Gomphonema angustatum angustatum (Kutz.) Rabenh. 1864
GO004A	Gomphonema gracile Ehrenb. 1838
GO013A	Gomphonema parvulum parvulum (Kutz.) Kutz. 1849
NA006A	Navicula mediocris Krasske 1932
NA009A	Navicula lanceolata (Agardh) Kutz.
NA013A	Navicula pseudoscutiformis Hust. 1930
NA014A	Navicula pupula pupula Kutz. 1844
NA017A	Navicula ventralis Krasske 1923
NA023A	Navicula gregaria Donk. 1861
NA032A	Navicula cocconeiformis cocconeiformis Greg. ex Greville 1855
NA033A	Navicula subtilissima Cleve 1891
NA037A	Navicula angusta Grun. 1860
NA038A	Navicula arvensis Hust.
NA038B	Navicula arvensis maior Lange-Bertalot 1985
NA046A	Navicula contenta contenta Grun. in Van Heurck 1885
NA099A	Navicula bremensis Hust. 1957
NA112D	Navicula minuscula muralis (Grun. in Van Heurck) Lange-Beralot in Lange-Bertalot & Rumrich 1981
NA114A	Navicula subrotundata Hust. 1945
NA581A	Navicula pseudobryophila Hust. 1942
NA751A	Navicula cryptotenella Lange-Bertalot 1985
NA779A	Navicula pseudoarvensis Hustedt 1942
NA9999	Navicula sp.
NE036A	Neidium ampliatum (Ehren) Krammer 1985
NI002A	Nitzschia fonticola Grun. in Van Heurck 1881
NI005A	Nitzschia perminuta (Grun. in Van Heurck) M. Perag. 1903
NI008A	Nitzschia frustulum (Kutz.) Grun. in Cleve & Grun. 1880
NI009A	Nitzschia palea palea (Kutz.) W. Sm. 1856
NI020A	Nitzschia angustata angustata (W. Sm.) Grun. in Cleve & Grun. 1880
NI031C	Nitzschia linearis subtilis (Grun) Hustedt 1923
NI033A	Nitzschia paleacea (Grun. in Cleve & Grun.) Grun. in Van Heurck 1881
NI193A	Nitzschia perminuta (Grun.) M. Perag. 1903
NI216A	Nitzschia pura Hustedt 1954
NI9999	Nitzschia sp.
PE002A	Peronia fibula (Breb. ex Kutz.) R. Ross 1956
PI001A	Pinnularia gibba (Ehrenb.) Ehrenb. 1843
PI011A	Pinnularia microstauron microstauron (Ehrenb.) Cleve 1891
PI014A	Pinnularia appendiculata (Ag.) Cleve 1896
PI022A	Pinnularia subcapitata subcapitata Greg. 1856
PI056A	Pinnularia rupestris Hantzsch in Rabenh. 1861
PI9999	Pinnularia sp.
RE001A	Reimeria sinuata (Greg.) Kociolek & Stoermer 1987
RH9999	Rhopalodia sp.
SA001A	Stauroneis anceps anceps Ehrenb. 1843
SP006A	Stenopterobia curvula (W Smith) Krammer 1987
SY009A	Synedra nana Meister 1912
SY013A	Synedra tenera W. Sm. 1856
TA001A	Tabellaria flocculosa flocculosa (Roth) Kutz. 1844

Appendix 2 Summary diatom results for each sample in Loch Langavat core LGVT1

1. Sample depth 0-0.5 cm (sample date 2003)
Slide: 28796; Totcount: 400; Number of taxa: 41

Ten Most Abundant Taxa:

%	
43.5	CY002A Cyclotella pseudostelligera
17.5	AS001A Asterionella formosa
5.75	AC013A Achnanthes minutissima
5.25	TA001A Tabellaria flocculosa
4.75	CY9987 Cyclotella [cf. comensis]
2.25	FR005D Fragilaria virescens exigua
2	BR010A Brachysira neoexilis
1.5	FR009H Fragilaria capucina gracilis
1.5	GO013A Gomphonema parvulum
1.5	NA779A Navicula pseudoarvensis

2. Sample depth 1-1.5 cm (sample date ~1999)
Slide: 28797;Totcount: 425; Number of taxa: 46

Ten Most Abundant Taxa:

%	
31.06	AS001A Asterionella formosa
25.65	CY002A Cyclotella pseudostelligera
6.12	TA001A Tabellaria flocculosa
5.65	AC013A Achnanthes minutissima
4.71	FR005D Fragilaria virescens exigua
2.82	CY9987 Cyclotella [cf. comensis]
1.88	FR009H Fragilaria capucina gracilis
1.88	SY009A Synedra nana
1.65	CY006B Cyclotella kuetzingiana planetophora
1.41	BR010A Brachysira neoexilis

3. Sample depth 2-2.5 cm (sample date ~1995)
Slide: 28798; Totcount: 402; Number of taxa: 55

Ten Most Abundant Taxa:

%	
27.61	AS001A Asterionella formosa
10.45	FR005D Fragilaria virescens exigua
9.95	AC013A Achnanthes minutissima
9.45	TA001A Tabellaria flocculosa
6.47	CY002A Cyclotella pseudostelligera
3.73	CY9987 Cyclotella [cf. comensis]
2.99	BR001A Brachysira vitrea
1.99	NA779A Navicula pseudoarvensis
1.74	FU002A Frustulia rhomboides
1.49	BR010A Brachysira neoexilis

4. Sample depth 4-4.5 cm (sample date ~1990)
Slide: 28799; Totcount: 351; Number of taxa: 60

Ten Most Abundant Taxa:

%	
13.96	AS001A Asterionella formosa
8.55	BR010A Brachysira neoexilis
8.26	FR005D Fragilaria virescens exigua
7.12	CY006B Cyclotella kuetzingiana planetophora
5.41	AC013A Achnanthes minutissima
4.84	CY9987 Cyclotella [cf. comensis]
3.99	TA001A Tabellaria flocculosa
3.42	CM018A Cymbella gracilis
3.13	BR001A Brachysira vitrea
2.56	FU002A Frustulia rhomboides

5. Sample depth 10-10.5 cm (sample date ~1950)
Slide: 28802; Totcount: 361; Number of taxa: 57

Ten Most Abundant Taxa:

%	
18.84	CY9987 Cyclotella [cf. comensis]
12.19	AC013A Achnanthes minutissima
12.19	FR005D Fragilaria virescens exigua 1881
8.59	BR010A Brachysira neoexilis
4.16	TA001A Tabellaria flocculosa
3.05	BR001A Brachysira vitrea
3.05	CM018A Cymbella gracilis
2.77	CY006B Cyclotella kuetzingiana planetophora
2.77	EU047A Eunotia incisa
2.22	CY002A Cyclotella pseudostelligera

6. Sample depth 30-30.5 cm (sample date ~1850)
Slide: 28808; Totcount: 368; Number of taxa: 58

Ten Most Abundant Taxa:

%	
26.09	CY9987 Cyclotella [cf. comensis]
14.67	AC013A Achnanthes minutissima
7.07	FR005D Fragilaria virescens exigua
5.98	CY010A Cyclotella comensis
4.08	CY006B Cyclotella kuetzingiana planetophora
3.8	BR001A Brachysira vitrea
3.8	BR010A Brachysira neoexilis
2.45	CM018A Cymbella gracilis
2.17	FR002C Fragilaria construens venter
1.9	AC004A Achnanthes pseudoswazi