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Palaeoecological study of seven mesotrophic lochs

Final Report to SEPA and SNH

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Executive summary

This is the final report to the Scottish Environment Protection Agency and Scottish Natural Heritage on the ‘Palaeoecological study of seven mesotrophic lochs’. The aim of the project was to employ multi-proxy palaeoecological methods (diatoms, Cladocera, plant macrofossils) to define reference conditions and to assess ecological changes in the seven lochs over approximately the last 100-150 years and hence to provide valuable information to assist with the development of environmental improvement plans for these sites. The study sites were Tangy Loch, Loch Nan Gad, Loch a Phuill, Loch Flemington, Monk Myre, White Loch and Monzievaird. These are all sites of high conservation interest currently or having once supported the biodiversity priority species *Najas flexilis* (slender naiad) or *Potamogeton rutilis* (Shetland pondweed).

Sediment cores were collected from the seven lochs in January-February 2006. An open water and a littoral core were taken from each site with the exception of Loch a Phuill where organic sediments could be found in only one bay. The cores were extruded in the field, stratigraphic changes were noted and the percentage dry weight and organic matter content of each core were subsequently determined in the laboratory. Sediment samples from each of the open water cores were analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs and ^{241}Am by direct gamma assay in order to provide radiometric dates. Reasonable chronologies were established for six of the cores and indicated that the records covered a period of at least 100-150 years, although there was evidence of sediment focusing at White Loch. At the seventh site, Tangy Loch, very low concentrations of ^{210}Pb and ^{137}Cs were detected and, therefore, a reliable chronology could not be produced for this site.

Screening of selected subsamples from each of the seven open water cores revealed that diatom preservation was sufficient to proceed with full diatom analysis at all sites except Loch a Phuill. Here there was marked dissolution and an abundance of broken valves and, therefore, further analysis was not undertaken. Screening of the Cladocera remains in the open water cores indicated that there were plentiful remains in Loch Nan Gad, Monk Myre and White Loch but fewer remains were observed in the cores from Tangy Loch, Monzievaird and particularly Loch Flemington. Cladocera remains were very sparse in the Loch a Phuill core. Consequently, twelve samples were analysed from the former three lochs and a lower resolution of six samples were analysed from Tangy Loch and Monzievaird. Cladocera analysis was not carried out at Loch Flemington and Loch a Phuill. The macrofossil screening exercise on the littoral cores from Tangy Loch, Loch Nan Gad, Loch Flemington and Monzievaird revealed that macrofossil remains were relatively abundant and, therefore, full macrofossil analysis was carried out on all four cores. The spheroidal carbonaceous particle (SCP) method was employed in an attempt to date the four littoral cores. However, this met with limited success. Both TANG2 and NGAD2 had very short SCP profiles with low concentrations and the only chronological information that could be gained was the depth in the core at which samples post-dated 1850 AD. The SCP profiles from MONZ2 and FLEM2 were considerably longer and were approximately an order of magnitude higher than those in TANG2 and NGAD2. However, both profiles were very irregular suggesting frequent and considerable changes in sediment accumulation at the coring locations. Due to the uncertainties surrounding the data, the chronological information derived from the SCP analyses must be treated with caution.

The multi-proxy palaeoecological analyses were carried out to assess changes in ecosystem structure and function of the study lochs. Diatom and Cladocera assemblages were used to identify changes in the algal flora and fauna, respectively,

but also to infer changes in productivity and habitat availability. The plant macrofossil record was analysed to determine changes in the aquatic plant communities of the sites. The key findings for each loch are as follows:

At Tangy Loch, the data indicate that it is a naturally nutrient-poor loch, formerly supporting an oligo-mesotrophic flora comprised of *Nitella, Isoetes, Lobelia* and broad-leaved *Potamogeton* spp. The loch remains in good condition with a diverse aquatic macrophyte community. Nevertheless, it has experienced enrichment leading to an increase in planktonic production. The data also suggest that there have been structural changes with compositional shifts in the flora and fauna, and an increase in plant species richness and biomass.

At Loch Nan Gad, the data indicate that it is a naturally nutrient-poor, mildly acidic loch, formerly supporting an oligotrophic flora comprised of *Isoetes, Lobelia, Nitella* and both broad and fine-leaved *Potamogeton* spp. The loch is currently in good condition and supports a healthy and diverse plant community. Whilst the palaeo-data provide evidence of slight enrichment with an increase in plant abundance and diversity, and increased planktonic production, over the period represented by the cores, none of the plant taxa observed in the lower part of the core have been lost from the record

At Loch Flemington, the data indicate that the site formerly supported a diverse plant community typical of a mesotrophic loch, dominated by *Nitella* with *Myriophyllum alterniflorum, Callitriche, Ranunculus*, *Potamogeton praelongus* and *P. obtusifolius.* The sediment record indicates that the loch has experienced complete turnover in its plant community with presently no taxa in common with those observed in the reference assemblages. The loch underwent an initial phase of species shifts at around 1850 with a period of high diversity, before undergoing a further phase of enrichment resulting in a loss of plant diversity and marked compositional changes.

At Monk Myre, the data indicate that the loch formerly supported diatom and Cladocera communities typical of a mesotrophic loch. These have both undergone changes associated with enrichment over approximately the last 150 years, most notably during ~1950-1970. Whilst the benthic and plant-associated diatom and Cladocera assemblages reflect the continued presence of plants, the degree of change in both biological groups indicates there is likely to have been significant alterations in the submerged macrophyte flora of the site.

At White Loch, the data indicate that the site formerly supported a diverse, largely non-planktonic diatom community typical of a mesotrophic loch. However, the diatom flora has undergone changes associated with enrichment, initially in ~1980 with a further phase in the late 1990s, resulting in an increase in the planktonic component. Whilst the Cladocera data indicate that plants have been abundant throughout the period represented by the core and that a diverse plant community is likely to be present today, the shifts may reflect a change in the species composition of the submerged macrophyte flora.

At Monzievaird, the data indicate that the site formerly supported a diverse, species-rich plant community typical of an oligo-mesotrophic loch, comprised of several *Potamogeton* species (including P. *crispus, obtusifolius, friesii/compressus*), *Callitriche*, *Nitella, Chara, Ranunculus, Lobelia, Ceratophyllum* and *Nymphaeaceae.* However, all of the biological elements experience marked and synchronous changes over the period represented by the cores, indicative of enrichment. The data suggest that the present day plant community has few taxa in common with those observed in the reference assemblages, having undergone an initial phase of species losses at around 1900 with *Nymphaeaceae* becoming the dominant component of the aquatic vegetation, before undergoing a further phase of enrichment from ~1980 resulting in a loss of plant diversity and marked compositional changes with dominance of taxa associated with relatively productive waters. The cladoceran ephippia data suggest a change in ecological functioning coincident with the step change in the macrofossil flora.

Given that only six samples were analysed for macrofossils at Lochs Tangy and Nan Gad, the addition of six further samples for macrofossil analysis is recommended. Macrofossil analyses were not carried out at White Loch and Monk Myre yet given the marked changes in the diatom and Cladocera assemblages in cores from these sites, full macrofossil analysis is recommended to assess changes in the aquatic plant community over the last century, and particularly over the last few decades.

The study produced some interesting findings with respect to the biodiversity priority species, *Najas flexilis*. In Lochs Tangy and Nan Gad, *Najas flexilis* appears only relatively recently in the macrofossil record suggesting that it has not always been present at these sites, most probably because the conditions were too unproductive in the past. In Monzievaird, the current presence of the species was indicated by the occurrence of remains in the surface sample even though *Najas flexilis* had not been recorded in recent surveys. It is possible that the species was missed as the survey employed only shoreline methods and hence a snorkel based survey and continued monitoring is recommended. In Lochs Tangy and Nan Gad the palaeo-data in the uppermost samples confirmed recent presence of the species as recorded in modern surveys. At Loch Flemington the macrofossil record indicated that *Najas flexilis* has been present in the loch for at least the last 100 years and is still present today even though it is not identified as a biodiversity priority species for this site.

The study has successfully determined the reference communities and the degree of ecological change in six of the seven lochs over approximately the last 100-150 years. The information will hopefully make a valuable contribution to the development of environmental improvement plans for these sites.

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Cover photograph: Piston coring at White Loch

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SPECIFICATION AND OBJECTIVES

The aim of the project was to employ multi-proxy palaeoecological methods (diatoms, Cladocera, plant macrofossils) to define reference conditions and to assess ecological changes in seven mesotrophic lochs over approximately the last 100-150 years and hence to provide valuable information to assist with development of environmental improvement plans for these sites. The study sites were Tangy Loch, Loch Nan Gad, Loch a Phuill, Loch Flemington, Monk Myre, White Loch and Monzievaird. These are all sites of high conservation interest currently or having once supported the biodiversity priority species *Najas flexilis* or *Potamogeton rutilis*.

The work programme was comprised of two phases, as follows:

Phase 1

1. Collect an open water and littoral core from each loch

2. a) Extrude the cores in the field at 1 cm intervals
   b) Describe the cores
   c) Measure dry weight and organic matter content of selected levels of the open water cores
   d) Store the littoral cores in the sediment archive for potential future work.

3. Undertake radiometric dating of the open water cores to establish a chronology.

Phase 2

1. Prepare six selected samples from the seven open water cores for diatoms to assess degree of preservation and to determine whether there are any shifts in the diatom assemblages.

2. Carry out full diatom analysis on 12 samples per core on each of the cores selected in point 1. Calculate diatom-inferred total phosphorus (DI-TP) (where appropriate) and chord distance measures of floristic change.

3. Prepare six selected samples from the seven open water cores for cladocera screening to assess potential for a full cladocera analysis.

4. Carry out full Cladocera analysis on 12 samples per core on each of the cores selected in point 3.

5. Screen littoral cores for plant macrofossil remains from four lochs selected by SEPA for potential macrofossil analysis.

6. Select two of the four cores screened in point 5, based on quality of macrofossil remains, for spheroidal carbonaceous particle (SCP) analysis to provide chronologies.

7. If the SCP results indicate that the two selected cores can be adequately dated then carry out full plant macrofossil analysis on 12 samples per core.

It should be noted that, in consultation with SEPA and SNH, the above work programme was slightly revised following screening of the cores for the fossil remains of the various groups. Full diatom analysis was carried out on all cores except Loch a Phuill although a lower resolution of six samples were analysed from the Tangy Loch core; Cladocera analysis was carried out on 12 samples from Loch Nan Gad, Monk Myre and White Loch and at a lower resolution of six samples from

Tangy Loch and Monzievaird; plant macrofossil analysis was undertaken on 12 samples from Loch Flemington and Monzievaird and at a lower resolution of six samples in Tangy Loch and Loch Nan Gad. Following discussion with SEPA and SNH, it was agreed that a small amount of additional funding would be made available in order to carry out spheroidal carbonaceous particle (SCP) analysis on all four littoral cores selected for plant macrofossil analysis in an attempt to provide chronologies.

METHODS

Core collection

A total of 13 sediment cores, approximately 1 m long, were collected between 24 January and 1 February 2006 using a piston coring device. Cores were taken from two locations in each loch; one from the open water and one from the marginal/littoral zone, and locations were recorded by GPS. An area of accumulating sediment could not be found in Loch a'chlair, Tiree and therefore the nearby Loch a Phuill was sampled in its place. In Loch a Phuill a sediment depth greater than a few centimetres was found only in one sheltered bay and thus a single core from this location was retrieved.

Water depth, secchi depth, water colour, pH and conductivity were measured at each loch, and site and catchment details were noted. Summary details of the cores are given in Table 1.

Extrusion and core description

The cores were extruded in the field at 1 cm intervals and any visible 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 in the laboratory on alternate samples from each core by standard techniques (Dean, 1974). The %DW and %LOI measurements have been completed on all of the open water and littoral cores. In almost all cases the pair of cores from each site was not sufficiently similar in their %DW or %LOI profiles to enable correlation by this method. Therefore, once littoral cores are selected for plant macrofossil analysis, independent dating will be achieved through spheroidal carbonaceous particle analysis.

Radiometric dating

A reliable method of establishing a chronology for sediment cores is to use radiometric dating techniques (Appleby, 2001). ^{210}Pb occurs naturally in lake sediments as one of the radioisotopes in the ^{238}U decay series. It has a half-life of 22.26 years, making it suitable for dating sediments laid down over the past 100-150 years. The total ^{210}Pb activity in sediments comprises supported and unsupported ^{210}Pb. In most samples the supported ^{210}Pb can be assumed to be in radioactive equilibrium with ^{226}Ra and the unsupported activity at any level of a core is obtained by subtracting the ^{226}Ra activity from the total ^{210}Pb (Appleby *et al*., 1986).

^{210}Pb dates for sediment cores can be calculated using both the constant rate of ^{210}Pb supply (CRS) model and the constant initial ^{210}Pb concentration (CIC) model (Appleby & Oldfield, 1978). The CRS model is most widely accepted; it assumes that the ^{210}Pb supply is dominated by direct atmospheric fallout, resulting in a constant rate of supply of ^{210}Pb from the lake waters to the sediments irrespective of net dry mass accumulation rate changes. If there are interruptions to the ^{210}Pb supply, for example sediment focusing, dates are calculated either by the CIC model or by using a composite of both models. The factors controlling the choice of model are described in full in Appleby & Oldfield (1983).

^{137}Cs (half-life 30 years) and ^{241}Am are artificially produced radionuclides, introduced to the study area by atmospheric fallout from nuclear weapons testing and nuclear reactor accidents. ^{137}Cs activity in sediments prior to the 1986 Chernobyl nuclear accident derives mainly from nuclear weapons testing fallout. Where this isotope is strongly adsorbed on to sediments, the activity versus depth profile is presumed to reflect varying fallout rate and useful chronological markers are provided by the onset of ^{137}Cs fallout in 1954, and peak fallout in 1963.

Sediment samples from each of the open water cores were analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs and ^{241}Am by direct gamma assay in the Bloomsbury Environment Institute at University College London using either an ORTEC HPGe GWL series well-type, or an ORTEC HPGe LOAX series planar-type, coaxial low background intrinsic germanium detector. Lead-210 was determined via its gamma emissions at 46.5keV, and ^{226}Ra by the 295keV and 352keV gamma rays emitted by its daughter isotope ^{214}Pb following three weeks storage in sealed containers to allow radioactive equilibration. Cesium-137 and ^{241}Am were measured by their emissions at 662kev and 59.5kev. The absolute efficiencies of the detector were determined using calibrated sources and sediment samples of known activity. Corrections were made for the effect of self absorption of low energy gamma rays within the sample. The raw data are presented in Appendix 1 and the chronologies are described below.

Spheroidal carbonaceous particle analysis

Dating of the littoral cores from four selected sites, Tangy Loch, Loch Nan Gad, Loch Flemington and Monzievaird, was carried out using the well established technique of spheroidal carbonaceous particle (SCP) described in Rose (1994) and Rose *et al*. (1995). Dried sediment was subjected to sequential chemical attack by mineral acids to remove unwanted fractions leaving a suspension of mainly carbonaceous material and a few persistent minerals in water. 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 SCPs 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 criteria for SCP identification under the light microscope followed Rose (submitted). Analytical blanks and SCP reference material (Rose, submitted) were included in each batch of sample digestions. The detection limit for the technique is c. 100 gDM^{-1} and concentrations have an accuracy of c. ± 45 gDM^{-1}.

It should be noted that a good chronology cannot be guaranteed and indeed problems have arisen when using SCPs to date previous cores taken from marginal zones from a number of lakes (Neil Rose, pers comm.). It may be over optimistic to expect that the SCP concentration profiles in littoral cores exhibit the features characteristic of profiles in sediment cores taken from deep water areas, albeit that these features are regularly observed in all areas of the UK (Rose *et al*., 1995) and further afield (Rose *et al*., 1999). The radiometric dating technique is, unfortunately, also problematic in some systems, particularly shallow, wind-stressed lakes (e.g. Bennion *et al*., 2001) and on balance the SCP method was considered to be preferable for dating the littoral cores in the present study. Given the nature of the SCP profiles in the four littoral cores, the cumulative percentage SCP approach to sediment dating (Rose & Appleby, 2005) could not be used. Instead, the 'traditional' dating features of the start of the SCP record, the rapid increase in SCP concentration as a result of the post-War increase in demand for electricity, and the SCP concentration peak were used to assign dates. In Scotland these features are ascribed the dates 1850 ± 25, 1950 ± 15 and 1978 ± 5, respectively.

Diatom analysis

Diatom slides were prepared from selected sub-samples of the seven open water cores using standard techniques (Battarbee, 1986). Six slides from each core were scanned to assess degree of preservation and to determine whether there were any shifts in the diatom assemblages using a Leitz research microscope with a 100x oil immersion objective and phase contrast. Principal floras used in identification were Krammer & Lange-Bertalot (1986-1991). Subsequently, full diatom analysis was undertaken on selected sub-samples from all open water cores with the exception of Loch a Phuill. At five lochs, 12 samples from each core were analysed and in Tangy Loch only six samples were counted. A minimum of 300 valves were identified in each sample. All diatom data are expressed as percentage relative abundance.

An existing diatom transfer function was applied to the diatom data for each core, following taxonomic harmonisation between the training set and the fossil data. Reconstructions of diatom-inferred total phosphorus (DI-TP) were produced using a Northwest European training set of 152 relatively small, shallow lakes (< 10 m maximum depth) with annual mean TP concentrations ranging from 5-1200 µg TP l^{-1} and a median value for the dataset of 104 µg TP L^{-1} (Bennion *et al*., 1996). The model performs well and has a low root mean squared error of prediction (RMSEP) of 0.21 $\log_{10}$ µg TP L^{-1} for the weighted averaging partial least squares two-component (WA-PLS2) model (ter Braak & Juggins 1993; Bennion *et al*., 1996). All reconstructions were implemented using C2 (Juggins, 2003). The accuracy of the reconstructions was assessed by comparison of the DI-TP value for the surface sample with current measured mean TP concentrations from the SEPA database. However it should be noted that this acts only as a guide and that, owing to high variability in TP concentrations, particularly in nutrient rich waters, the measured range of TP values is considerable at some lochs.

Cladocera analysis

Cladocera are microscopic crustaceans (zooplankton) and are represented in lake sediments by a variety of body parts. They can be used to infer changes in fish population density and shifts in habitat structure (i.e. macrophytes), particularly in shallow lakes (e.g. Jeppesen *et al*., 1996, 2001). For the cladocera analysis 12 levels from NGAD1, MONK1 and WHE1, and six levels from TANG1 and MONZ1 were examined. The selected sub-samples were prepared using an adaptation of the standard sub-fossil Cladocera preparation technique (Korhola & Rautio 2001). This method is based on that currently employed by colleagues working on Danish lakes (Jeppesen *et al*., 1996; Jeppesen, 1998). For each sample at least 5 cm^3 of sediment was heated in a deflocculating agent (10% potassium hydroxide, KOH) and sieved at 150 µm and 50 µm. The retents of the two sieves were then washed into separate pots and safranin stain was added. A sub-sample (of known volume) was screened with a compound microscope and the chitinous remains of the Cladocera were identified with reference to Flössner (1972), Frey (1958, 1959) and Alonso (1996). Carapaces, head-shields and post-abdomens were recorded separately. All Cladocera data are expressed as percentage relative abundance.

Plant macrofossil and zooplankton ephippia analysis

For the macrofossil analysis 12 levels from MONZ2 and FLEM2, and six levels from NGAD2 and TANG2 were examined. A measured volume of sediment (~ 30 cm^3, the exact volume was assessed using water displacement) was analysed for each level. Samples were sieved at 350 and 125 microns and the residues from each were transferred using distilled water to plastic vials for storage. The entire residue from the 350 micron sieve was examined under a stereomicroscope at magnifications of x10-40 and plant and animal macrofossils (mostly zooplankton ephippia) were identified and enumerated. A quantitative sub-sample, approximately one fifth of the sample, from the 125 micron sieve sample was analysed for smaller remains such as leaf spines. All material was identified by comparison with herbarium documented reference material.

It was not always possible to ascribe remains to species level, thus in some cases an aggregate group of species corresponding to the highest possible taxonomic resolution was used. For example, *Potamogeton pusillus* agg. included remains of *P. pusillus* and *P. berchtoldii*. Distinct morphotypes of *Chara* oospores were also identified and presented as *Chara* oospores A, B or C. The data are presented as numbers of remains per 100 cm^3 of wet sediment.

Data analysis

Summary statistics of the biological data (diatoms, Cladocera, plant macrofossils) were calculated for each sample in the cores including the number of taxa observed and the Hill's N2 diversity score (Hill & Gauch, 1980). The results of the biological analyses were plotted as stratigraphic diagrams using C2 (Juggins, 2003). For diatoms and Cladocera the data are presented as bars with a line joining each sample to better illustrate the main shifts in the records. However, for plant macrofossils (and zooplankton ephippia) the data are presented as bars only as the data are expressed as numbers rather than percentages and are relatively noisy owing to the differential production of remains by each plant (e.g. Charophytes produce abundant oospores whereas *Potamogeton* spp. produce relatively few seeds).

Cluster analysis was performed on the core data (where there were at least 12 samples) to identify the major zones in the diatom, Cladocera and plant macrofossil profiles, respectively, using CONISS (Grimm, 1987), implemented by TGView version 2.0.2 (Grimm, 2004). CONISS is a program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Zones are illustrated on the stratigraphic plots for each biological group in order to facilitate description of the major compositional changes. Where the number of samples analysed was fewer than 12 cluster analysis was considered to be inappropriate.

The degree of floristic change in the diatom assemblages and faunistic change in the Cladocera asssemblages between the bottom sample and every other sample in each core was assessed using the squared chord distance (SCD) dissimilarity coefficient (Overpeck *et al*. 1985) implemented in C2 (Juggins, 2003). This is preferred to other dissimilarity measures as it maximises the signal to noise ratio, it performs well with percentage data and has sound mathematical properties (Overpeck *et al*. 1985). The scores range from 0 to 2 whereby 0 indicates that two samples are exactly the same and 2 that they are completely different. Scores less than 0.29, 0.39, 0.48 and 0.58 indicate insignificant change at the 1st, 2.5th, 5th and 10th percentile, respectively (Simpson, 2005). It is advised that the 2.5th percentile (score <0.39) is used here to define sites with low change between the bottom and every other sample. This is more stringent than the 5th percentile (score <0.48) used in previous similar studies (e.g. Bennion *et al*., 2004) and reflects revised thinking on the use of the chord distance statistic. This revision follows closer examination of sediment sample diatom data from over 200 UK lake cores held in the ECRCs in-house AMPHORA database whereby unimpacted sites typically have chord distance values of <0.4 (in many cases <0.3) between core top and bottom samples (e.g. Bennion, 2004). The original selection of the 5th percentile to indicate low change was developed based on between site comparisons where one has to account for natural variability (background noise) in the dataset – the result of natural differences between sites - and to reflect that no two sites will ever be perfectly similar in practise (Simpson, 2005; Simpson *et al*., 2005). The SCD scores were not calculated for the macrofossil assemblages owing to the difficulty of applying this technique to abundance data, especially where the amount of the identifiable remains varies between plant taxa.

Indirect ordination techniques (principal components analysis – PCA) (ter Braak & Prentice, 1988) were used to analyse the variance downcore within the diatom, Cladocera and plant macrofossil assemblages, respectively, using CANOCO version 4.5 (ter Braak & Smilauer, 2002). The technique summarises the main changes in the data and helps to identify zones of change within complex species-rich data sets. The sample scores for PCA axis 1 are given. Where scores between two neighbouring samples in the core differ markedly this indicates that the assemblages have undergone substantial change between these two points in the core. The scores are also plotted in the stratigraphic diagrams to illustrate the timing of any shifts and whether these were gradual or abrupt.

Table 1 Details of the sediment cores collected from the seven study sites

NAME	WBID	NGR	CORING DATE	SITE CODE	CORE CODE	CORING WATER DEPTH (M)	CORING LOCATION	CORE LENGTH (CM)	CORE TYPE	SECCHI DEPTH (m)	WATER COLOUR	pH	COND (uS/cm)	CATCHMENT NOTES	LOCH NOTES
Tangy Loch	27234	NR695280	24/01/06	CZNR62	TANG1	open: 1.88	NR69624, 27848	100	Fat piston	0.83	brown, peaty	5.5	67	coniferous plantation, rough grazing, wind farm	stony littoral and Juncus in marginal zone; Littorella, Myriophyllum, Elodea
					TANG2	littoral: 1.57	NR69666, 27768	73	Fat piston						
Loch Nan Gad	26482	NR787575	25/01/06	NGAD	NGAD1	open: 1.62	NR78420, 57201	139	Fat piston	1.3	brown, peaty	7.6	129	50% coniferous, rough grazing (sheep)	Emergents in marginal & shallow zones (Carex rostrata, Schoenoplectus); Juncus bulbosus, Potamogeton polygonifolius, Pot natans, Lobelia common, Littorella present
					NGAD2	littoral: 1.57	NR78537, 57281	94	Fat piston						
Loch a'Chlair	23548	NL983445	26/01/06	ACHR		<0.6 m all over	NO CORE TAKEN. NO SEDIMENT								
Loch a Phuill	23618		27/01/06	PHUI	PHUI1	open: 0.95	NL95334, 41752	46	Fat piston	>1	clear	7.26	414	Rough pasture, common land, sand dunes	all loch <1.4 m deep with mostly sandy bottom; Fontinalis in margins; otters; Myriophyllum spicatum, Chara and Littorella in western bay

NAME	WBID	NGR	CORING DATE	SITE CODE	CORE CODE	CORING WATER DEPTH (M)	CORING LOCATION	CORE LENGTH (CM)	CORE TYPE	SECCHI DEPTH (m)	WATER COLOUR	pH	COND (uS/cm)	CATCHMENT NOTES	LOCH NOTES
Loch Flemington	17013	NH802523	29/01/06	FLEM	FLEM1	open: 2.2	NH81254, 52223	125	Fat piston	2.2	clear	7.3	341	Gorse scrub, deciduous woodland, coniferous plantation, rough and semi-improved pasture	Carex, Equisetum and Juncus in margins; Pot natans; abundant wildfowl (> 50 swans)
					FLEM2	littoral: 1.4	NH80913, 52063	82	Fat piston						
Monk Myre	23610	NO210437	30/01/06	MONK	MONK1	open: 2.5	NO20899, 442774	151	Fat piston	2.5	clear	7.33	228	Market gardening (soft fruits), arable, deciduous trees	Phragmites and Carex in margins; fishing club
					MONK2	littoral: 1.6	NO21103, 42795	86	Fat piston						
White Loch	23607	NO170429	30/01/06	WHIE	WHIE1	open: 11.2	NO16968, 42937	88	Fat piston	2.4	clear	7.27	208	Arable, Scots pine, large house/gardens	Phragmites beds; fishing club
					WHIE2	littoral: 1.64	NO17090, 42848	98	Fat piston						
Monzievaird	24171	NN841234	01/02/06	MONZ	MONZ1	open: 9.4	NN83768, 23241	90	Fat piston	4.25	clear	7.45	95	Mixed woodland, road to south, chalet development	Phragmites margins, grassy banks, Potamogeton lucens; frozen water (2 inch ice)
					MONZ2	littoral: 2.9	NN83777, 23292	105	Fat piston						

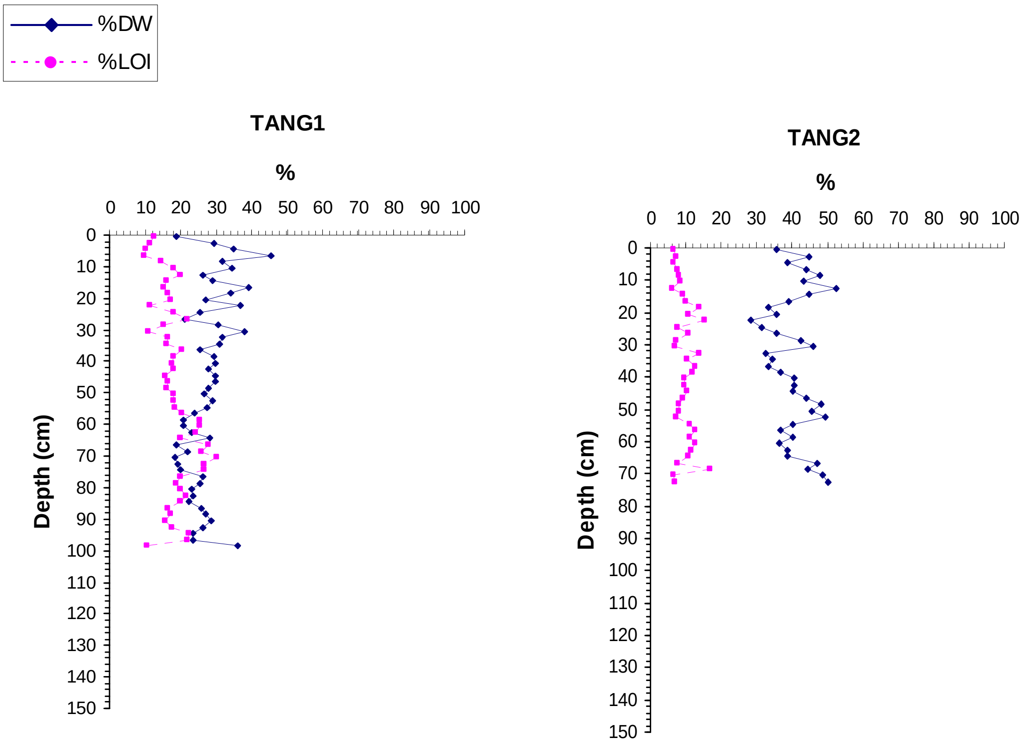
RESULTS AND DISCUSSION

1. Tangy Loch

Core description

The open water core, TANG1, was relatively organic in the lower section with decreasing %LOI from a peak of ~30% at 70 cm to ~10% at the top (Figure 1). The littoral core, TANG2, had a more stable %LOI profile with generally low organic matter content of less than 10%.

Figure 1 Percentage dry weight and organic matter profiles of TANG1 & TANG2



Radiometric dating

Lead-210 Activity

^{210}Pb concentrations in excess of the supporting ^{226}Ra were above limits of detection down to a depth of between 6 and 7.5 cm in TANG1. Unsupported ^{210}Pb concentration dropped sharply from the surface sediments, suggesting sedimentation rates declined in the top 2 cm of the core. Below 2 cm unsupported ^{210}Pb concentrations were very low, with a mean value of ~22 ± Bq kg^{-1}, implying a ^{210}Pb dating horizon of not more than ~60 years. The unsupported ^{210}Pb inventory in the core was 1179 Bq m^{-2}. This corresponds to a mean ^{210}Pb supply of 36.7 Bq m^{-2} y^{-1}, approximately 50% of the estimated atmospheric flux, and it is therefore uncertain whether this core has a complete record of modern sediments.

Artificial Fallout Radionuclides

The ^{137}Cs record was of little chronological value. There were no subsurface peaks to identify either the 1986 or 1963 depths. ^{241}Am was not detected.

Core Chronology

The ^{210}Pb chronology was calculated using the CRS dating model (Table 2). Use of the CIC model was precluded by the non-monotonic variation in unsupported ^{210}Pb activity. The ^{210}Pb calculations suggest that sedimentation rates in this core vary with a general increase from the beginning of the twentieth century to the 1950s, followed by a decline to the present day. However, little confidence can be attached to these results without corroborating evidence.

Table 2 TANG1 Chronology

Tangy Loch CRS Model Pb-210 Chronology								
Core TANG1								
Code 1	Date 2006							
210-Pb flux = 36.7 +/- 3.0 Bq/m^2/yr								
90% Equilibrium depth = 4.8 cm, or 1.54 g/cm^2								
99% Equilibrium depth = 6.7 cm, or 2.31 g/cm^2								
Depth	Drymass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	1178.8	2006	0				
0.5	0.1386	779.2	1993	13	1	0.0124	0.042	9.6
1	0.2772	650.1	1987	19	3	0.0136	0.044	14.9
1.5	0.4408	492.8	1978	28	4	0.0187	0.059	22.8
2	0.6043	373.5	1969	37	6	0.0238	0.074	30.6
2.5	0.7679	283.1	1960	46	7	0.0289	0.088	38.5
3	0.9315	243.1	1955	51	9	0.0342	0.105	52.1
3.5	1.095	208.7	1950	56	10	0.0395	0.121	65.8
4	1.2586	172.8	1944	62	12	0.029	0.086	59
4.5	1.4222	143	1938	68	14	0.0184	0.05	52.1
5	1.6252	87.5	1922	84	16	0.0134	0.035	59.9
5.5	1.8282	53.5	1907	99	18	0.0083	0.02	67.6

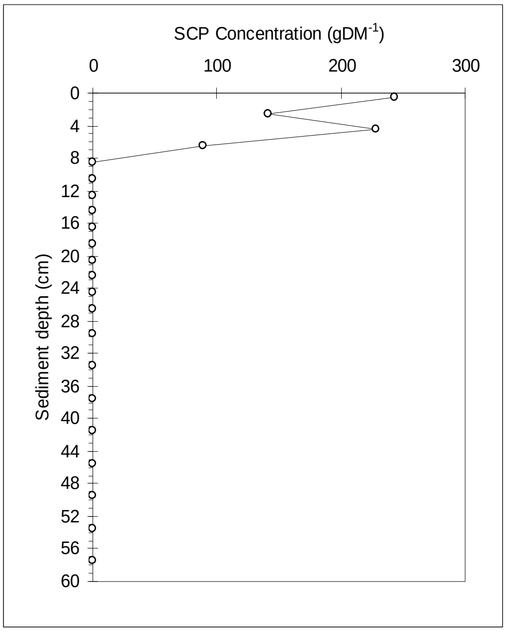
Spheroidal carbonaceous particle analysis

TANG2 has a very short SCP profile with SCP presence only in the upper 7 cm and at low concentrations (Table 3, Figure 2). This profile could be indicative of an area of temporary sediment storage, i.e. accumulation of recent sediments prior to their movement away from littoral areas to deeper water, although there is no suggestion of this from the lithostratigraphic data. It may be that the lower levels of the core, below those containing SCPs, represent 'old' sediment and that there is a hiatus in conformable accumulation at this point in the record. However, this is just speculation. Therefore, no chronological information is available from this profile except that the levels above 7 cm are more recent than 1850.

Table 3 TANG2: SCP concentrations

Sediment depth (cm)	SCP concentration (gDM^{-1})	± 90% confidence limit (gDM^{-1})
0 – 1	243	168
2 – 3	142	139
4 – 5	228	158
6 – 7	89	87
8 – 9	0	0
10 – 11	0	0
12 – 13	0	0
14 – 15	0	0
16 – 17	0	0
18 – 19	0	0
20 – 21	0	0
22 – 23	0	0
24 – 25	0	0
26 – 27	0	0
29 – 30	0	0
33 – 34	0	0
37 – 38	0	0
41 – 42	0	0
45 – 46	0	0
49 – 50	0	0
53 – 54	0	0
57 - 58	0	0

Figure 2 TANG2: SCP concentration profile



Biological analyses

Diatom analysis

Six samples were analysed for diatoms in the TANG1 core (Table 4). A total of 131 diatom taxa were observed in the core with between ~50-80 taxa per sample, and the results for the major taxa are shown in Figure 3. The assemblages throughout the core were diverse, particularly in the three upper samples, and comprised of non-planktonic forms, *Cyclotella radiosa* being the only notable planktonic species. The most abundant diatoms were benthic *Fragilaria* and small *Navicula* taxa, which are typically found in shallow lakes, and these exhibited only small changes throughout the period represented by the core. A number of subtle changes were observed in the diatom assemblages, however, with slight increases in *Cyclotella radiosa*, *Cocconeis placentula*, *Navicula jaernfeltii* and *Achnanthes minutissima* at the expense of the *Fragilaria* spp. in the upper 40 cm. This could indicate a slight increase in productivity as *Cyclotella radiosa* is a planktonic diatom found in mesotrophic waters, and *Cocconeis placentula* and *Achnanthes minutissima* are often found attached to plant surfaces and, therefore, their expansion could be associated with an increase in plant biomass in the loch. The PCA axis 1 scores (Figure 3) illustrate that the changes have been gradual. Unfortunately, owing to uncertainties surrounding the radiometric dating results for TANG1, dates cannot be assigned to the core with any confidence and thus the timing of these changes cannot be established. It seems unlikely that the last 100 years are represented by only the upper 5 cm. The subtle species shifts are reflected in the relatively low SCD scores (Table 4). However, the SCD values in the upper three samples (above 40 cm) exceed 0.6 indicating that the diatom flora has experienced moderate change from reference condition.

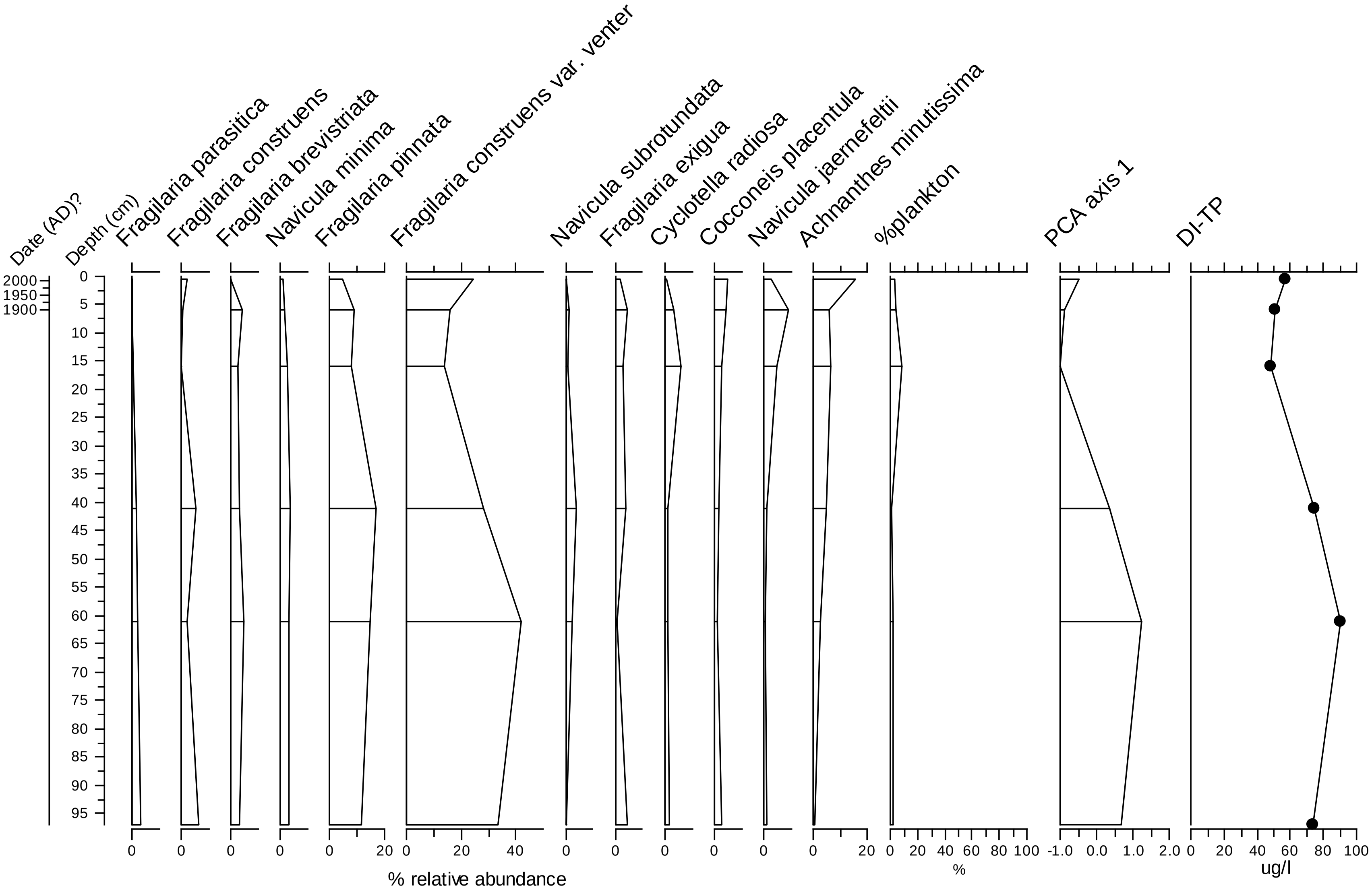
The ecological interpretation is not supported by the DI-TP results which suggest that the loch had concentrations of ~75-90 µg l^{-1} in the early period and then experienced a decline to values of ~50-60 µg l^{-1} in the upper 40 cm of the core. The transfer function appears to over-estimate TP concentrations for Tangy Loch based on comparison with SEPA data from the outflow for February 2005, and April and June 2006, which gives a mean TP of ~15 µg l^{-1}. There are two likely explanations for this: i) dominance of benthic *Fragilaria* spp. swamps the signal as these are cosmopolitan taxa with a wide TP tolerance and hence are poor indicators of changes in nutrient concentrations (Bennion *et al*., 2001), and ii) the transfer function has few lakes with TP concentrations as low as Tangy Loch and therefore the model over-estimates values for this site.

In summary, the diatom assemblages exhibit only minor changes, possibly associated with an increase in plant biomass, and there is no evidence of marked enrichment or any major habitat shifts.

Table 4 Results of the diatom analysis on TANG1

Depth (cm)	No taxa	N2	DI-TP µg l^{-1}	SCD	PCA axis 1 scores
1	61	10.6	57	0.72	-0.4643
6	66	18.7	51	0.61	-0.8679
16	79	19.7	49	0.71	-0.9892
41	60	6.9	74	0.37	0.3785
61	53	4.5	90	0.37	1.2585
97	48	3.6	74	0.00	0.6844

Figure 3 Summary diatom diagram for TANG1



Cladocera analysis

The Cladocera screening exercise on TANG1 revealed that remains become less abundant down-core, with increases in vegetative matter making lower samples very difficult to count. On this basis, and given the poor chronology for this core, full analysis of only six samples was carried out and the results are shown in Table 5 and Figure 4.

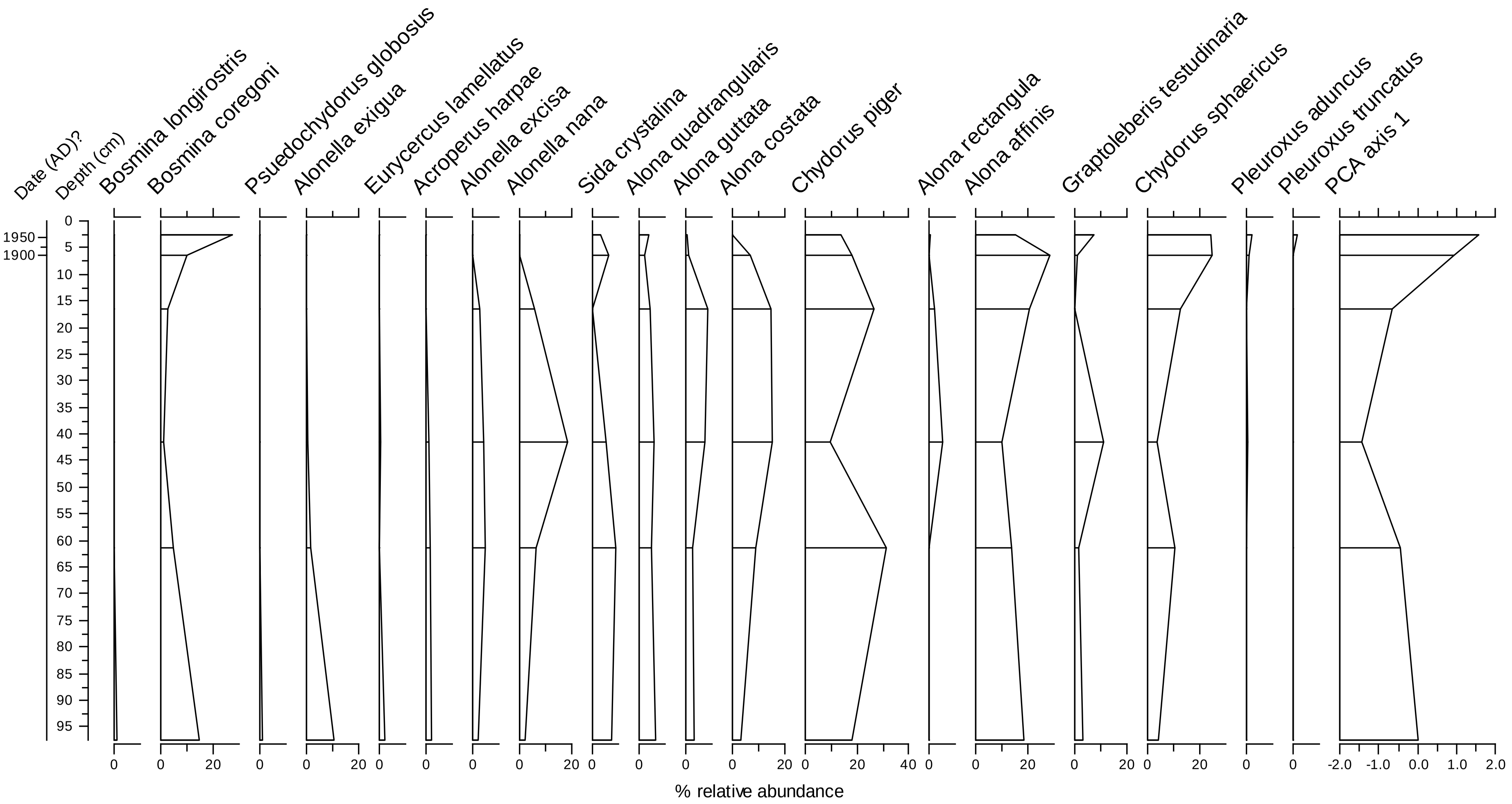
A total of 19 cladoceran species were found with species richness declining towards the top of the core (Table 5). PCA axis 1 scores indicate that cladoceran assemblages remain relatively stable up until the top 10 cm. *Alona affinis, Bosmina coregoni* and *Chydorus piger* are the dominant species in the lower part of the core. An increase in *Alonella nana* and *Graptoleberis testudinaria* is evident at 41.5 cm. However, by 16.5 cm this small shift is reversed with *Chydorus piger* and *Alona affinis* again being the dominant taxa. The main shift occurs in the top 10 cm of the core indicated by a fall in N2 values, increasing PCA axis 1 and SCD scores (Table 5) that show the greatest assemblage shift from the basal section of the core. This change is dated at pre-1900 AD although, as explained above, it is not possible to assign dates to this core with confidence. The majority of *Alona* species decline or disappear in the most recent sediments, while *Chydorus sphaericus* and the pelagic *Bosmina coregoni* increase in the top-most sample. Plant-associated *Pleuroxus* species are present in the upper samples, appearing for the first time in the record.

Overall, cladoceran assemblages remain relatively stable until the top 10 cm of the core although it is difficult to identify the timing of the changes due to poor chronological control.

Table 5 Results of the Cladocera analysis on TANG1

Depth (cm)	No taxa	N2	SCD	PCA axis 1 scores
2.5	11	5.37	0.42	1.5745
6.5	10	5.14	0.36	0.9258
16.5	10	6.13	0.44	-0.6432
41.5	16	9.31	0.43	-1.4309
61.5	13	6.48	0.18	-0.4495
97.5	16	8.60	0	0.0233

Figure 4 Summary Cladocera diagram for TANG1



Macrofossil analysis

The macrofossil screening exercise on the littoral core TANG2 revealed that macrofossil remains were relatively abundant and full macrofossil analysis on six samples was carried out.

Plant macrofossils

Analysis of six samples (Table 6) revealed that the two lower samples differed from the upper four samples and therefore the plant macrofossil assemblages are divided into two sections for description (Figure 5), although the exact timing of the changes cannot be established owing to the very short SCP record.

Pre ~1850 (50- 7 cm)

The lowermost sample was dominated by both fine-leaved and broad-leaved *Potamogeton* species, *Isoetes lacustris* and, to a lesser extent, *Isoetes echinospora* and *Lobelia* seeds. *Isoetes lacustris* and *Isoetes echinospora* reached maximum abundances in the lowermost sample. Oospores of *Nitella* and *Chara* morphotype B were also present. A large number of the smaller *Nitella* oospores (≤125 µm) were also found in the basal sample. The species present at 25 cm were similar to those at 50 cm but macrofossil remains generally decreased in abundance in the central section of the core and hence there was a shift in PCA axis 1 scores at this time.

Post ~1850 (7- 0 cm)

Remains of the small *Nitella* oospores (≤125 µm) and *Chara* oospores A and B increased after ~1850 AD (7 cm). However, oospore numbers were generally in the uppermost sample with the exception of *Chara* oospore morphotype C which was only present in the sub-surface sample (1 cm). The larger *Nitella* oospores, however, decreased after ~1850 AD and were absent from the 1 cm sample. The relatively low numbers of *Chara* and *Nitella* oospores in the 1 cm sample may be associated with the high water content and therefore interpretation of plant species abundance should be treated with caution in this sample.

Najas flexilis seeds were present continuously after ~1850 AD but were absent from the 1 cm sample. *Najas flexilis* leaf spines, however, were found in the uppermost sample suggesting that the plant was still present at the site during this time. Abundances of *Isoetes lacustris* and *Isoetes echinospora* were generally lower after ~1850 AD than in the lower section of the core. *Potamogeton* fine leaf species were also present after ~1850 AD but the broad leaf species were absent from the latter part of the record. The PCA axis 1 scores remained relatively stable in the upper section of the core.

Zooplankton ephippia

Ephippia remains were sparse in the lower two samples (pre-~1850 AD) in TANG2 forming a stark contrast to the remains in the upper four samples of the core (post-~1850) when ephippia remains became abundant (Figure 6). *Chydorid* spp and *Ceriodaphnia* spp increased at 7 cm and *Daphnia hyalina* agg and *Daphnia pulex* both increased at 3 cm with all species remaining relatively abundant in the sub-surface sample.

Table 6 Results of the plant macrofossil analysis on TANG2

Depth (cm)	No taxa	N2	PCA axis 1 scores
1	7	1.82	-0.3035
3	10	1.35	-0.5177
5	6	1.19	-0.5502
7	10	1.11	-0.5763
25	7	1.04	-0.2728
50	11	1.19	2.2205

Figure 5 Summary plant macrofossil diagram for TANG2

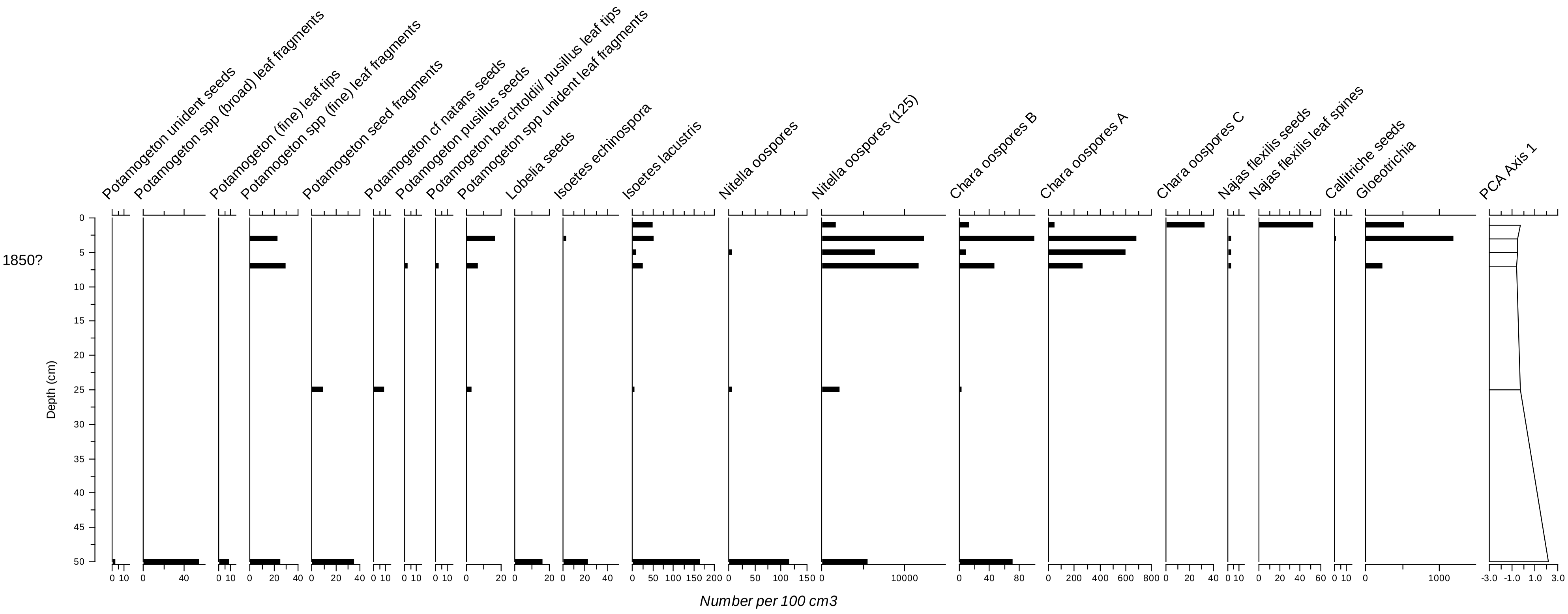
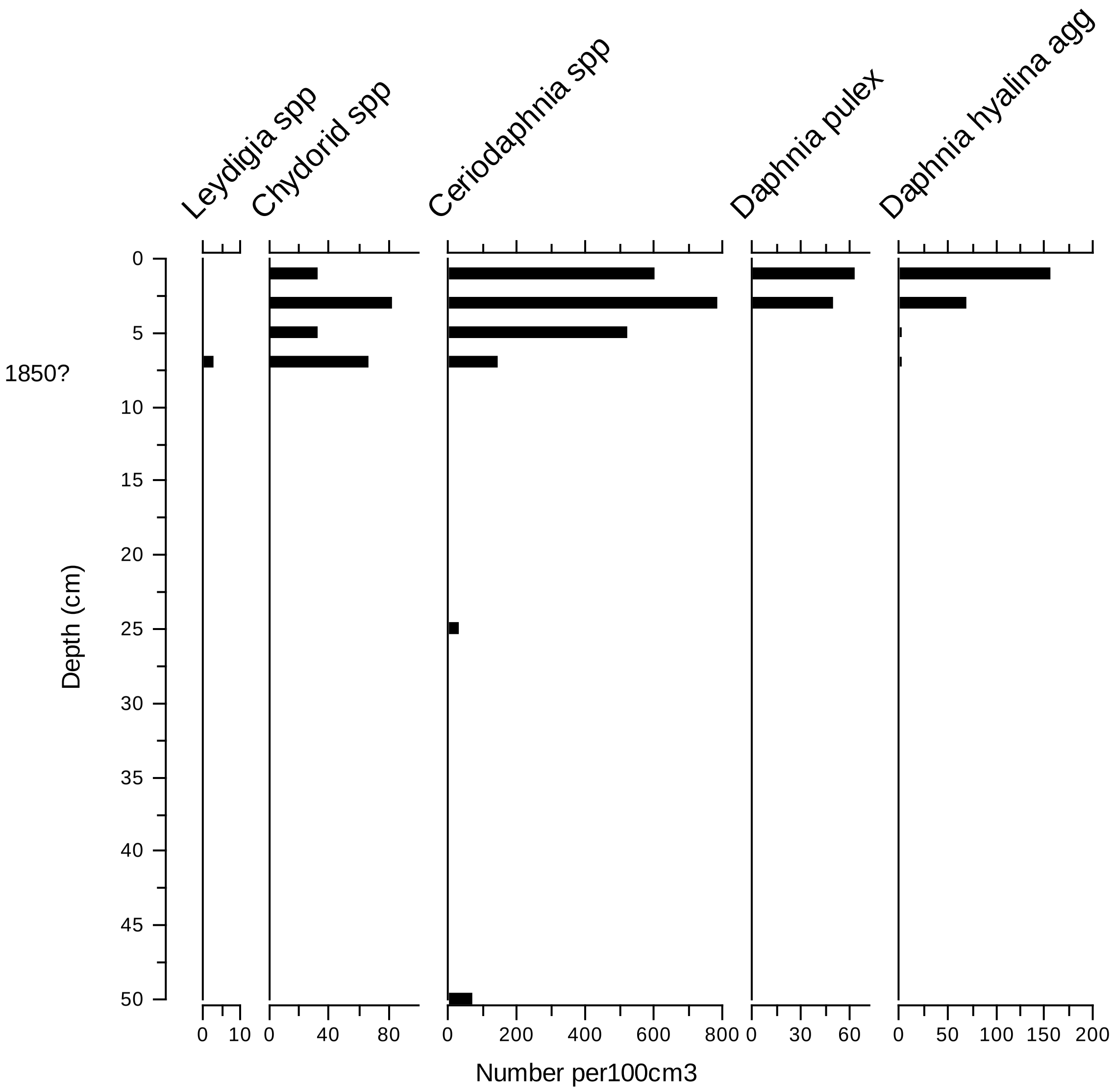


Figure 6 Summary zooplankton ephippia diagram for TANG2



Discussion

The palaeoecological data indicate that Tangy Loch is a naturally nutrient-poor loch, formerly supporting an oligo-mesotrophic flora comprised of *Nitella, Isoetes, Lobelia* and broad-leaved *Potamogeton* spp. There is evidence of slight enrichment over the period represented by the cores in the form of increased plant biomass, an increase in planktonic production (e.g. Vadeboncouer *et al*., 2003) and a shift in the dominant components of the aquatic vegetation. The plant macrofossil record indicates that whilst *Isoetes* is still present, *Lobelia* has very likely been lost and the broad-leaved *Potamogeton* taxa are absent from the uppermost samples, although one must interpret the macrofossil data of *Potamogeton* spp. with caution as remains are rare even when pondweeds are present. Currently the loch has a relatively species-rich plant community of *Isoetes lacustris*, fine-leaved *Potamogeton* spp., *Nitella*, several *Chara* spp. and notably *Najas flexilis*, the biodiversity priority species for this loch. However, *Najas flexilis* appears only relatively recently in the macrofossil record suggesting that it has not always been present at the site. The absence of *Najas* remains in the lower core suggests that the loch may have been too nutrient-poor to support it in the past as it is known to prefer relatively nutrient-rich conditions (Wingfield *et al*., 2005). In contrast to *Potamogeton* spp., *Najas* is a prolific seed producer and thus remains are likely to be found if the plant was present. The last record of *Najas flexilis* was from a snorkel survey conducted in 1998 (Wingfield *et al*., 2004) and, whilst it was not found in a repeat survey in 2000, its leaf fragments in the uppermost core sample indicate that the plant is still present in the loch.

Both the Cladocera and diatom records indicate increases in plant biomass and greater planktonic production. Unfortunately, owing to uncertainties surrounding the dating results, dates cannot be assigned to the core with any confidence and thus the timing of these changes cannot be established. The Cladocera record indicates that plants have been present throughout the period represented by the sediment core. However, relative increases in plant associated taxa (e.g. *Graptoleberis testudinaria, Chydorus sphaericus, Pleuroxus* spp.) (Hann, 1989) in the upper core suggest an increase in plant biomass. The increase in *Bosmina coregoni* is indicative of greater planktonic production as this species feeds on planktonic algae. The record of chitinous cladoceran remains is enhanced by the ephippia data which concur with the findings of the other proxies in that the higher numbers of *Chydorid* spp. in the upper core suggest increased plant abundance, and the increase in pelagic *Daphinia* and *Ceriodaphnia* indicates greater availability of planktonic algae as a food source. The diatom record exhibits an increase in the centric, planktonic species, *Cyclotella radiosa* in the recent period thereby confirming the increase in planktonic production in the loch. Furthermore, the expansion of *Cocconeis placentula* and *Achnanthes minutissima* in the upper core is in agreement with the interpretation of increased plant biomass as these taxa are typically found attached to plant surfaces. Unfortunately, the ecological interpretation of the diatom data is not supported by the DI-TP results which suggest that the loch had concentrations of ~75-90 µg l^{-1} in the early period and then experienced a decline to values of ~50-60 µg l^{-1} in the upper 40 cm of the core. The transfer function appears to over-estimate TP concentrations for Tangy Loch owing to the dominance of benthic *Fragilaria* spp. which swamp the signal as these are cosmopolitan taxa with a wide TP tolerance (Bennion *et al*., 2001), and because the transfer function has few lakes with TP concentrations as low as Tangy Loch. On reflection, therefore, the model is not appropriate for this site.

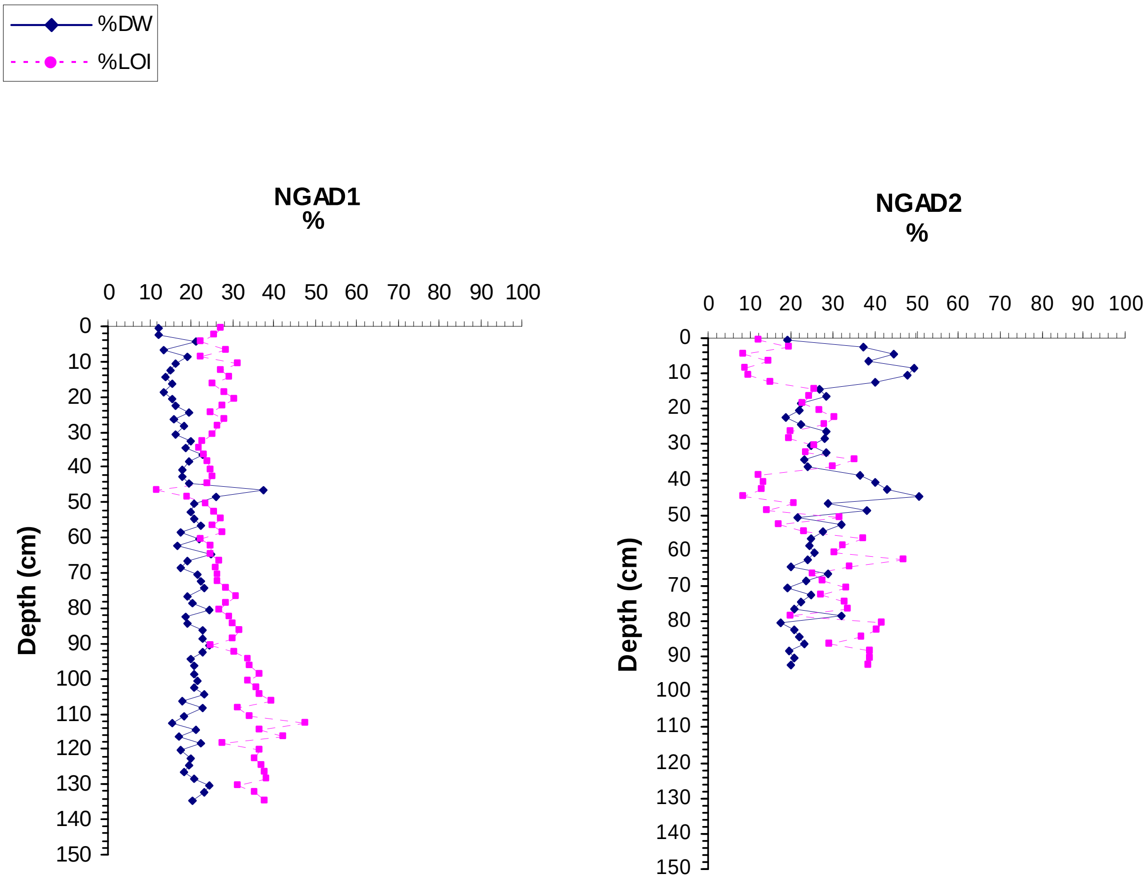
In summary, the palaeoecological data indicate that Tangy Loch remains in good condition with a diverse aquatic macrophyte community. Nevertheless, it has experienced enrichment leading to an increase in planktonic production. The data also suggest that there have been structural changes with compositional shifts in the flora and fauna, and an increase in plant species richness and biomass. Given that only six samples were analysed for this loch, the addition of several further samples from the early part of the record for macrofossil analysis is recommended to add greater certainty to the data interpretation.

2. Loch Nan Gad

Core description

The open water core, NGAD1, was relatively organic throughout with %LOI of ~30-40% (Figure 7). The littoral core, NGAD2, had a highly fluctuating %LOI profile with high organic matter below 50 cm and from ~15-38 cm, and low values from ~38-50 cm and in the upper 15 cm.

Figure 7 Percentage dry weight and organic matter profiles of NGAD1 & NGAD2



Radiometric dating

Lead-210 Activity

^{210}Pb concentrations in excess of the supporting ^{226}Ra were above limits of detection down to a depth of ~40 cm in core NGAD1. Unsupported ^{210}Pb concentration declined irregularly with depth, suggesting variable sedimentation rates in the core. Since concentrations were fairly low, standard errors are a little high and it is difficult to explain the fluctuations in the concentration profile.

Artificial Fallout Radionuclides

The ^{137}Cs record has two peaks. The peak at ~10.5 cm appears to provide a record of the 1963 fallout maximum from the atmospheric testing of nuclear weapons and is supported by a small peak of ^{241}Am record at the same depth. The peak at ~5.5 cm almost certainly records fallout of the 1986 Chernobyl accident.

Core Chronology

The ^{210}Pb chronology was calculated using the CRS dating models. Use of the CIC model was precluded by the non-monotonic variation in unsupported ^{210}Pb activity. The raw CRS dating model puts the 1963 layer at 14-15 cm (see Appendix 1), which is in poor agreement with the ^{137}Cs and ^{241}Am records, suggesting that there are changes in ^{210}Pb fluxes in the core. The corrected CRS ^{210}Pb dates using ^{137}Cs and ^{241}Am 1963 peaks are given in Table 7. The ^{210}Pb calculations suggest that sedimentation rates vary, with a general increase from the 1860s to the 1930s, followed by fluctuations to the present day.

Table 7 NGAD1 Chronology

CRS Pb-210 model corrected chronology							
Depth	Dry mass	Chronology			Sedimentation Rate		
		Date	Age	Std			% Std
cm	g/cm^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	2006	0				
1	0.1574	2002	4	2	0.0427	0.24	28.3
2	0.3399	1998	8	3	0.0423	0.235	33.5
3	0.5224	1994	12	3	0.0419	0.229	38.6
4	0.7049	1989	17	3	0.0415	0.224	43.8
5	0.8874	1985	21	3	0.0411	0.219	49
6	1.0783	1981	25	4	0.047	0.245	55.3
7	1.2777	1977	29	4	0.0592	0.302	62.7
8	1.4771	1974	32	4	0.0714	0.36	70.1
9	1.6765	1970	36	4	0.0651	0.329	79
10	1.8759	1965	41	4	0.0404	0.212	89.3
11	2.0596	1960	46	4	0.0537	0.3	22.3
12	2.2275	1957	49	4	0.057	0.333	25.9
13	2.3955	1953	53	4	0.0535	0.32	27
14	2.5634	1950	56	5	0.0431	0.262	25.5
15	2.7272	1946	60	5	0.0407	0.251	27.2
16	2.8868	1943	63	6	0.0465	0.289	32.1
17	3.0464	1939	67	7	0.0522	0.327	36.9
18	3.206	1936	70	7	0.052	0.321	39.5
19	3.3656	1932	74	8	0.0457	0.273	39.8
20	3.5252	1929	77	9	0.0395	0.225	40.1
21	3.7015	1924	82	10	0.0363	0.199	43.1
22	3.8946	1919	87	12	0.0361	0.195	48.8
23	4.0877	1913	93	14	0.036	0.191	54.5
24	4.2808	1908	98	16	0.0358	0.187	60.2

25	4.4739	1903	103	18	0.0357	0.183	65.9
26	4.6709	1896	110	19	0.0333	0.169	70.9
27	4.8719	1887	119	21	0.0286	0.145	75.3
28	5.0729	1878	128	22	0.024	0.121	79.7
29	5.2739	1869	137	23	0.0193	0.098	84.1
30	5.4749	1860	146	25	0.0147	0.074	88.5

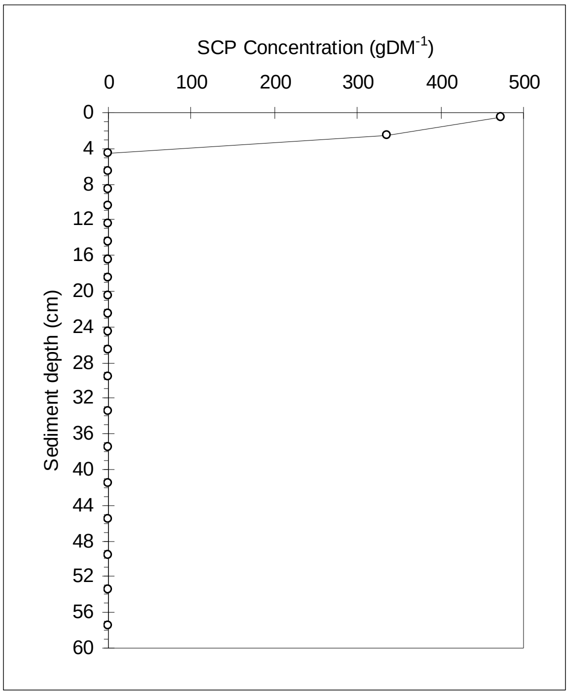
Spheroidal carbonaceous particle analysis

Similarly to TANG2, NGAD2 has a very short SCP profile with SCP presence only in the upper 3 cm and at low concentrations (Table 8, Figure 8). The interpretation is thus much the same as for the littoral core from Tangy Loch in that the profile could be indicative of an area of temporary sediment storage, although again there is no suggestion of this from the lithostratigraphic data. It may be that the lower levels of the core, below those containing SCPs, represent ‘old’ sediment and that there is a hiatus in conformable accumulation at this point in the record. However, this is just speculation. Therefore, no chronological information is available from this profile except that the levels above 3 cm are more recent than 1850.

Table 8 NGAD2: SCP concentrations

Sediment depth (cm)	SCP concentration (gDM^{-1})	± 90% confidence limit (gDM^{-1})
0 – 1	473	463
2 – 3	336	329
4 – 5	0	0
6 – 7	0	0
8 – 9	0	0
10 – 11	0	0
12 – 13	0	0
14 – 15	0	0
16 – 17	0	0
18 – 19	0	0
20 – 21	0	0
22 – 23	0	0
24 – 25	0	0
26 – 27	0	0
29 – 30	0	0
33 – 34	0	0
37 – 38	0	0
41 – 42	0	0
45 – 46	0	0
49 – 50	0	0
53 – 54	0	0
57 - 58	0	0

Figure 8 NGAD2: SCP concentration profile



Biological analyses

Diatom analysis

Seventeen samples were analysed for diatoms in the NGAD1 core (Table 9). The assemblages were very diverse with a total of 234 diatom taxa observed in the core and ~60-80 taxa in each sample. The results for the major taxa are shown in Figure 9. The core was dominated throughout by non-planktonic taxa typical of oligo-mesotrophic, slightly acid to circumneutral conditions, with a negligible amount of planktonic forms. The lake is shallow (< 2 m deep) with a large littoral zone and therefore a diverse non-planktonic diatom flora such as this might be expected. There were relatively minor shifts in the assemblages during the time period represented by the core with only two major zones identified by the cluster analysis: Zone 1 from the core base to ~22 cm (pre-1800s to ~1920) and Zone 2 from ~22 cm to the surface (~1920-present). Whilst the same dominant taxa were present in both zones, there was a slight increase in *Fragilaria construens* var *venter* and *Fragilaria exigua* in Zone 2, as well as in several *Cymbella* species, *Cocconeis placentula* var *euglypta* and *Eunotia incisa*. Likewise, the PCA axis 1 scores (Figure 9) illustrate that the diatom assemblages exhibited little change in the lower core but there is quite an abrupt compositional change at ~ 22 cm, dated to around 1920. The assemblages have experienced relatively little turnover since that time. The subtle species shifts are reflected in the relatively low SCD scores (Table 9). However, the SCD values in the upper core (above 8 cm, ~1974) exceed 0.6 indicating that the diatom flora has experienced moderate change from reference condition.

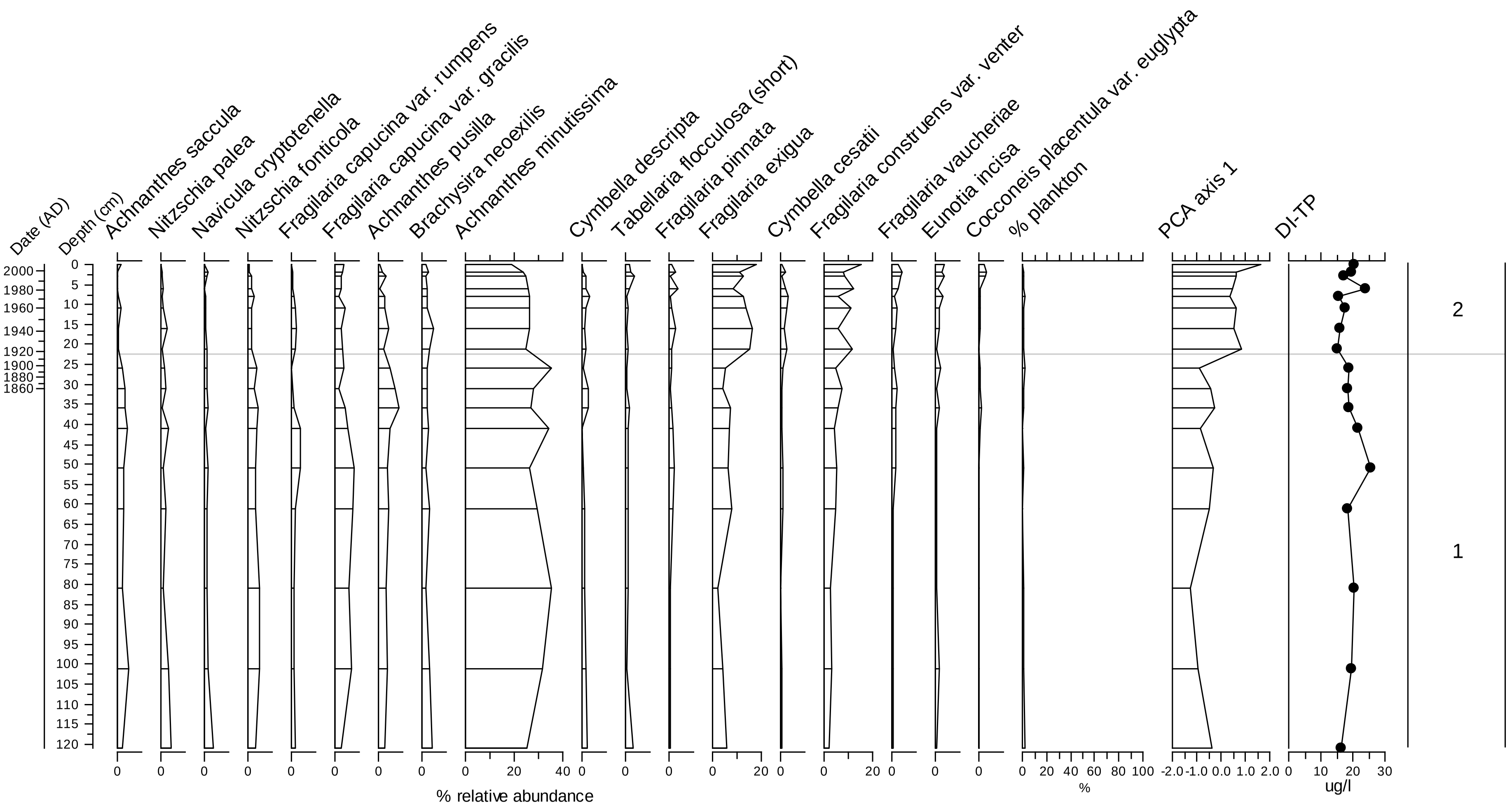
It is difficult to interpret these shifts in terms of ecological change but they could suggest an increase in plant biomass as many of the expanding taxa are commonly found attached to plant surfaces. There is no evidence of marked enrichment as the DI-TP values are relatively stable with concentrations of ~15-25 µg l^{-1} throughout the core. The DI-TP for the recent samples agrees well with the measured mean TP in the loch of 15 µg l^{-1} based on SEPA data from February, April and June 2006.

In summary, as for Tangy Loch, the diatom assemblages exhibit only minor changes possibly associated with an increase in plant biomass, and there is no evidence of marked enrichment.

Table 9 Results of the diatom analysis on NGAD1

Depth (cm)	No taxa	N2	DI-TP µg l^{-1}	SCD	PCA axis 1 scores
1	69	10.15	20.4	0.84	1.6566
2	65	11.63	19.5	0.68	0.6361
3	70	10.54	17.4	0.58	0.6223
6	72	10.26	23.9	0.61	0.4679
8	77	10.41	15.8	0.54	0.3645
11	74	9.25	17.7	0.57	0.6307
16	66	9.19	16.0	0.50	0.5198
21	68	9.44	15.3	0.52	0.8577
26	83	7.13	18.8	0.53	-0.8828
31	81	10.16	18.4	0.48	-0.4205
36	64	10.29	18.9	0.47	-0.2409
41	57	7.07	21.8	0.53	-0.8523
51	78	10.49	25.4	0.50	-0.3231
61	66	9.04	18.3	0.37	-0.4691
81	71	7.20	20.4	0.46	-1.2523
101	69	8.52	19.6	0.38	-0.9229
121	70	12.09	16.4	0.00	-0.3916

Figure 9 Summary diatom diagram for NGAD1



Cladocera analysis

The Cladocera screening exercise on NGAD1 revealed plentiful remains and full analysis of 12 samples was carried out, the results of which are shown in Figure 10. Zoning of the diagram with CONISS indicated two main assemblages split at 46 cm (pre-1860 AD). Overall, the sediments of NGAD1 are relatively rich in terms of cladoceran diversity (Table 10).

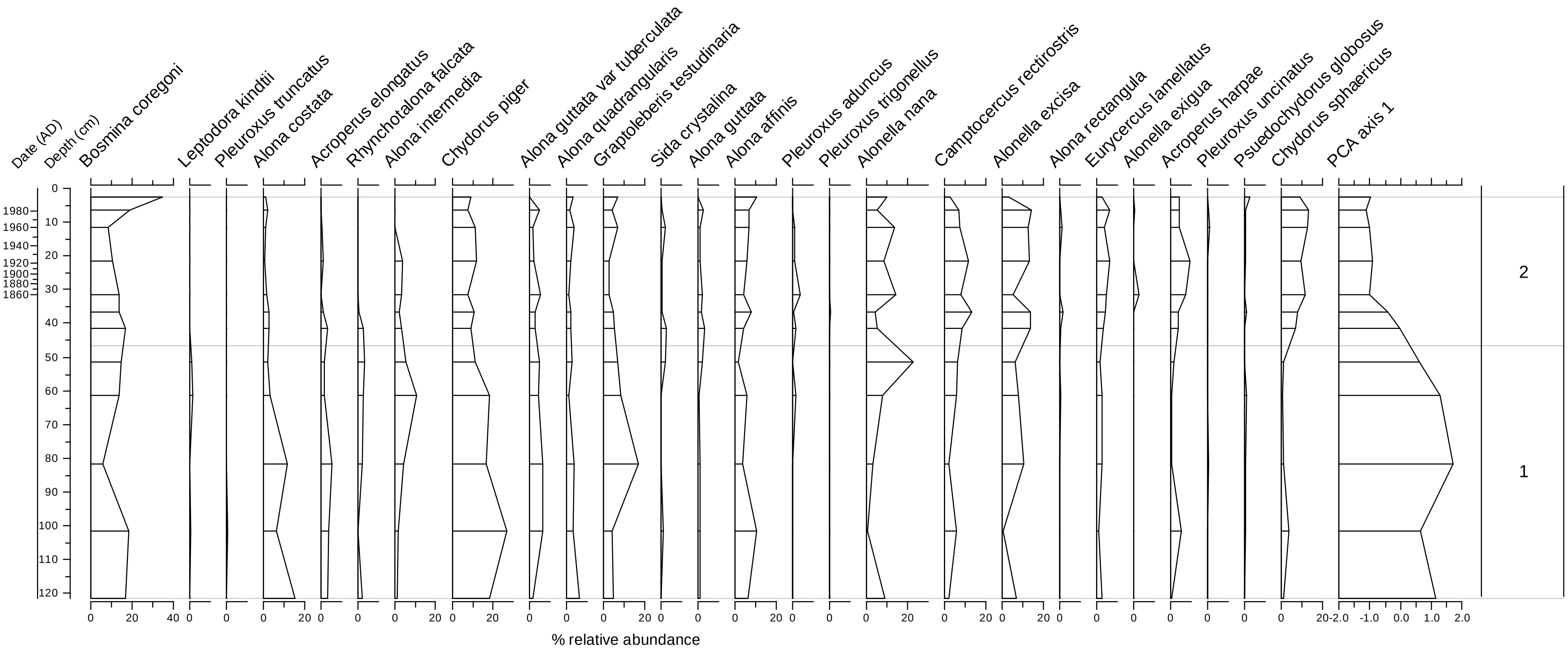
The lower section of the core (Zone 1) contained high proportions of *Bosmina coregoni* and *Chydorus piger,* although these taxa declined throughout the zone. Other species present include *Alona costata, Graptoleberis testudinaria* and *Alonella* species. The shift occurring at the boundary of Zones 1 and 2 is not, however, coincident with the largest shifts shown in the PCA axis 1 and SCD scores (Table 10) which indicate greatest change at around 30-40 cm (pre-1860 AD). The main difference here is that CONISS is not registering the start of a trend, but the acceleration of a change that has already begun slowly. The major species shifts were a decline in *Chydorus piger, Alona costata* and *Graptoleberis testudinaria* with concurrent increases in *Chydorus sphaericus, Acroperus harpae* and *Eurycercus lamellatus*. Throughout the upper section of Zone 2, the assemblage remained relatively stable. There was, however, a sharp resurgence of *Bosmina coregoni* in the upper 9 cm (from the mid-1970s). Species diversity, shown by N2 values and the number of taxa counted, also falls in the more recent sediments.

Overall, the main species changes in NGAD1 were between 30-50 cm with *Chydorus sphaericus* and *Acroperus harpae* beginning to establish at the expense of *Chydorus piger* and *Alona* species. Based on the chronology, this change occurred some time before ~1860 AD.

Table 10 Results of the Cladocera analysis on NGAD1

Depth (cm)	No taxa	N2	SCD	PCA axis 1 scores
2.5	16	5.93	0.33	-0.9795
6.5	19	9.80	0.31	-1.1245
11.5	20	11.07	0.30	-1.0049
21.5	19	11.15	0.33	-0.8931
31.5	18	11.83	0.35	-1.0122
36.5	22	11.29	0.24	-0.3917
41.5	20	12.16	0.20	-0.0315
51.5	22	9.40	0.19	0.6039
61.5	21	10.40	0.19	1.2809
81.5	23	10.13	0.14	1.7343
101.5	20	7.41	0.23	0.6603
121.5	21	9.04	0	1.1578

Figure 10 Summary Cladocera diagram for NGAD1



Macrofossil analysis

The macrofossil screening exercise on the littoral core NGAD2 revealed that macrofossil remains were relatively abundant and full macrofossil analysis of six samples was carried out (Table 11).

Plant macrofossils

The core has been divided into two sections for descriptive purposes and the results are shown in Figure 11.

Pre 1850 AD (50- 3 cm)

In the lowermost sample (50 cm) *Isoetes lacustris* and *Isoetes echinospora* remains were present in relatively low abundances. Both fine leaf and broad leaf *Potamogeton* species were present and occurred at their highest abundance within the basal sample. *Nymphaea alba* seed fragments were also found in this lowermost sample, in conjunction with small amounts of *Lobelia* seeds and oospores of *Nitella* and *Chara* oospores morphotype B. The sample at 25 cm was relatively sparse for macrofossil remains with the disappearance of the fine leaf and broad leaf *Potamogeton* species and *Isoetes echinospora*. *Isoetes lacustris* also decreased in abundance at this level along with fragments of *Nymphaea alba* seeds. Remains of *Lobelia* increased slightly during this period. The abundance and diversity of the macrofossil remains increased at 12 cm with the first recording of *Najas flexilis* leaf spines, *Potamogeton pusillus* type seeds and *Chara* oospores morphotype C. The assemblage changes are reflected in a slight shift in the PCA axis 1 scores at 12 cm.

Post 1850 AD (3- 0 cm)

Najas flexilis leaf spines, *Lobelia* seeds, *Potamogeton pusillus* type seeds, *Isoetes echinospora, Nitella* oospores and *Chara* oospores morphotypes B and C occurred in high abundances within the upper two samples. *Nymphaea alba* seed fragments, *Najas flexilis* seeds, *Callitriche* spp seeds and *Isoetes lacustris* remains also occurred in the sediments representing the post 1850 AD period. The PCA axis 1 scores show a slight increase at the surface of the core indicating that the species assemblage has changed slightly between the 3 cm and 1 cm samples.

Zooplankton ephippia

Ceriodaphnia spp were dominant in the lower section of NGAD2 (pre-~1850) along with small abundances of *Camptocercus rectirostris* and *Chydorid* spp (Figure 12). *Ceriodaphnia* spp began to decline at 12 cm and remained low in the post-~1850 AD period. *Daphnia hyalina* agg and *Daphnia pulex* both increased in the upper part of the core.

Table 11 Results of the plant macrofossil analysis on NGAD2

Depth (cm)	No taxa	N2	PCA axis 1 scores
1	15	6.33	1.4792
3	10	4.75	0.6772
5	10	4.69	0.3968
12	13	6.91	-0.0585
25	5	3.23	-1.047
50	8	3.35	-1.4478

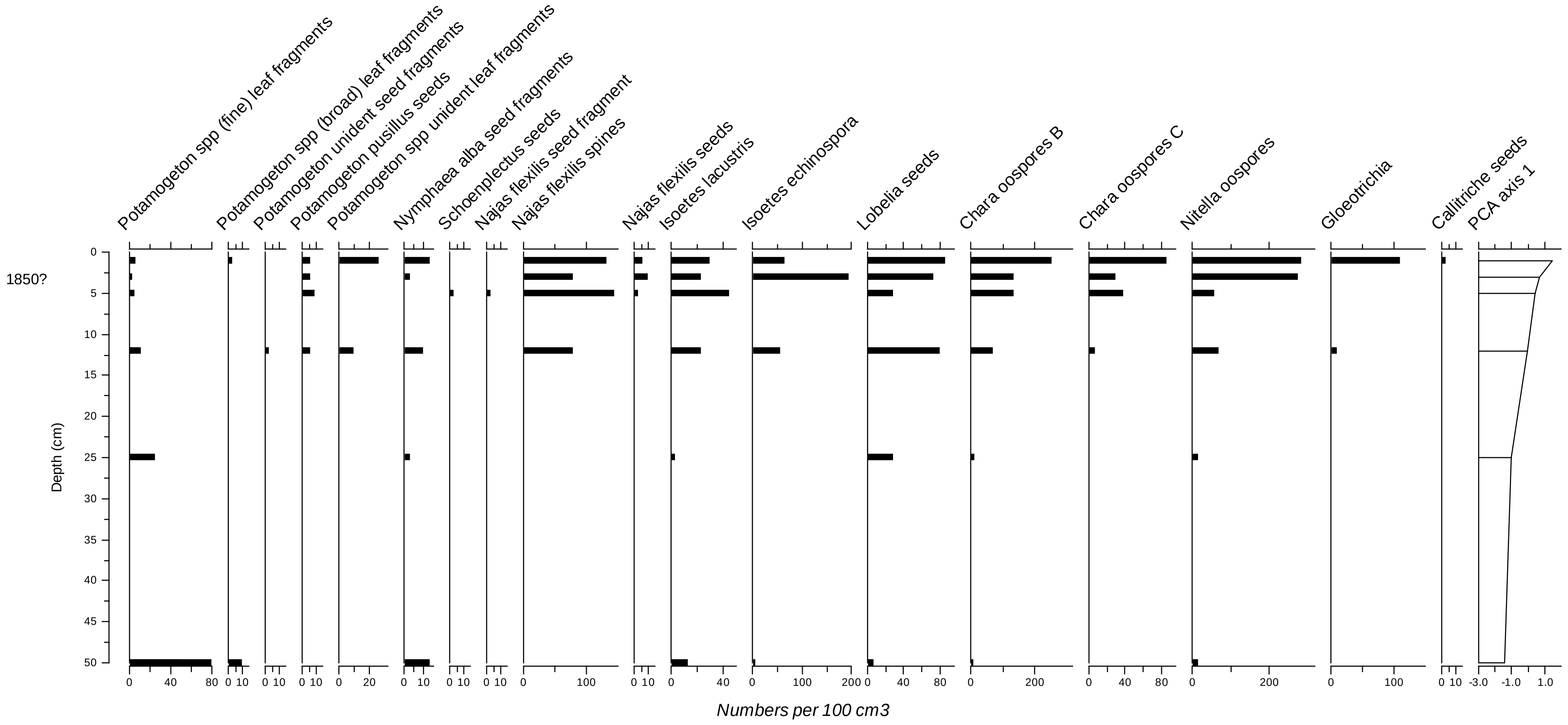
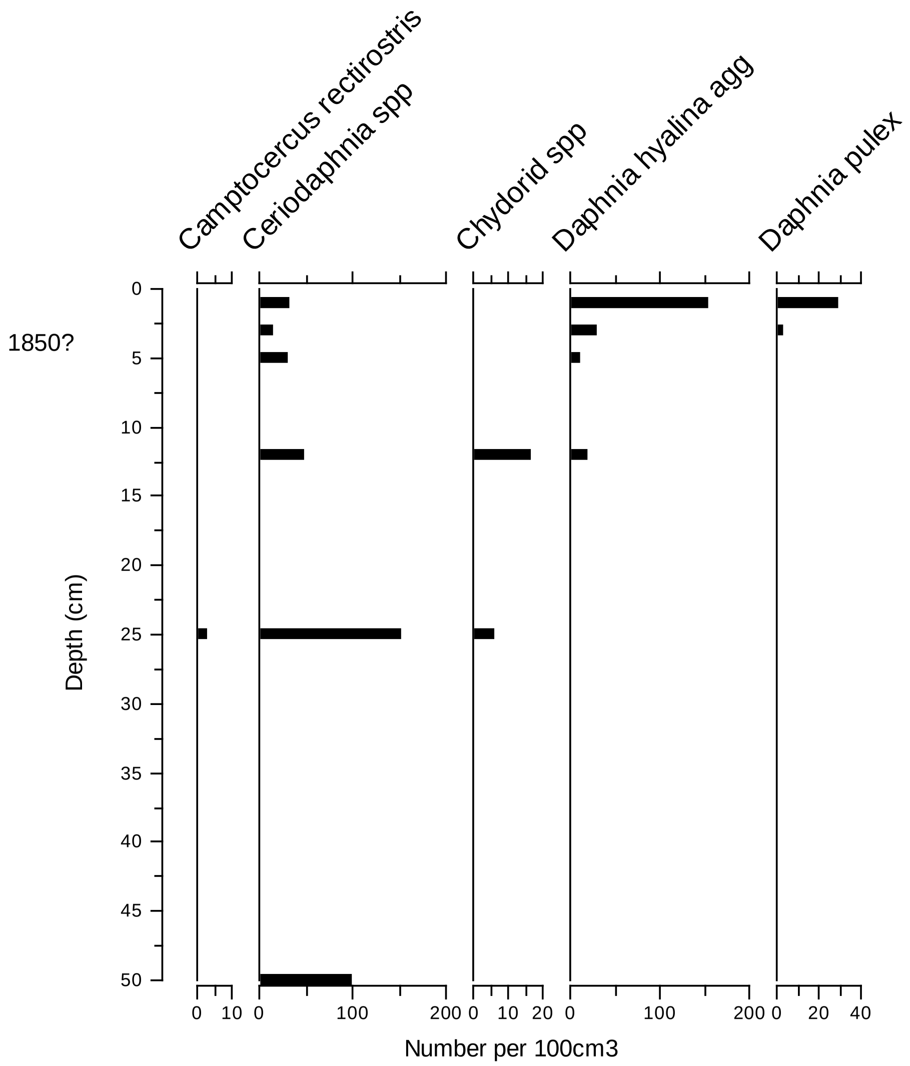


Figure 11 Summary plant macrofossil diagram for NGAD2

Figure 12 Summary zooplankton ephippia diagram for NGAD2



Discussion

The palaeoecological data indicate that Loch Nan Gad is a naturally nutrient-poor, mildly acidic loch, formerly supporting an oligotrophic flora comprised of *Isoetes, Lobelia, Nitella* and both broad and fine-leaved *Potamogeton* spp. Similarly to Tangy Loch, there is evidence of slight enrichment indicated by all biological groups, with a suggestion of increased plant biomass and diversity, and an increase in planktonic production. Nonetheless, the macrofossil data show that the plant community is currently diverse and healthy with two *Isoetes* species, *Lobelia, Nitella*, several *Chara* species, *Nymphaea alba*, both broad and fine-leaved *Potamogeton* spp. and *Najas flexilis*. In contrast to Tangy loch, Loch Nan Gad has lost none of the plant taxa that were observed in the reference samples at the base of the core. Notably, the remains of *Najas flexilis*, the biodiversity priority species for Loch Nan Gad, were not observed until the 12 cm sample suggesting that this species was not part of the community in the past, most likely because the loch was too unproductive. *Najas flexilis* was last recorded in the loch by snorkel survey methods in 1998 (Wingfield *et al.* 2004) and the palaeoecological data confirm its recent presence.

The diatom community is dominated throughout by non-planktonic, nutrient-poor, relatively acid-tolerant taxa but there are small increases in epiphytic taxa from ~1930s suggesting greater availability of plant surfaces to act as substrates. The DI-TP reconstruction indicates that nutrient concentrations have been relatively stable with values of ~15-25 µg l^{-1} throughout the core. Whilst the Cladocera record indicates that plants have been present in the loch during the whole period represented by the core, increases in plant-associated species such *as Eurycercus lamellatus, Acroperus harpae*, *Camptocercus rectirostris* and *Chydorus sphaericus* (Whiteside *et al*., 1978) in the upper section suggest higher plant biomass in recent times. There is evidence for increased planktonic production in the zooplankton data as the pelagic taxa, *Bosmina coregoni* and *Daphnia* spp, are present in greater numbers in the upper part of the cores. However, the functional shifts indicated by the Cladocera and diatom data are less pronounced than at Tangy Loch and appear to have had little impact on the higher plant community.

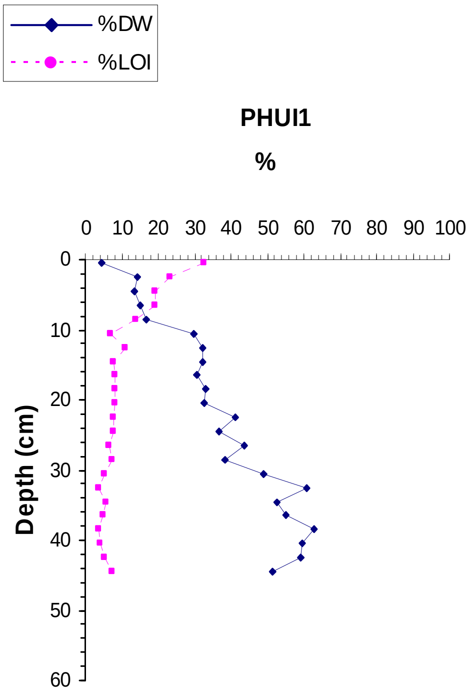
In summary, Loch Nan Gad is in good condition and supports a healthy and diverse plant community. The palaeoecological record provides evidence of slight enrichment with an increase in plant abundance and diversity, and increased planktonic production, over the period represented by the cores. Importantly, none of the plant taxa observed in the lower part of the core have been lost from the record. Given that only six samples were analysed for this loch, the addition of several further samples for macrofossil analysis is recommended to add greater certainty to the interpretation.

3. Loch a Phuill

Core description

In Loch a Phuill a sediment depth greater than a few centimetres was found only in one sheltered bay and thus a single core from this location (PHUI1) was retrieved. The core was dense and inorganic in the lower section, especially below 30 cm where the sediments contained a high percentage of sand (Figure 13). The %LOI increased steadily from ~10% at 10 cm to ~30% at the surface and conversely the dry weight values gradually decreased towards the core top.

Figure 13 Percentage dry weight and organic matter profiles of PHUI1



Radiometric dating

Lead-210 Activity

Total ^{210}Pb activity appears to reach equilibrium with the supporting ^{226}Ra at a depth of ~30-34 cm in core PHUI1. Unsupported ^{210}Pb activities, calculated by subtracting 226Ra activity from total ^{210}Pb activity, decline more or less exponentially with depth from the surface to ~15 cm and from 19 to 30 cm. However, there is a change in between those two sections, indicating relatively uniform sedimentation from 0 to 15 cm and from 19 to 30 cm.

Artificial Fallout Radionuclides

The ^{137}Cs activity declined with depth and was of little chronological value. Traces of ^{241}Am were detected between 10 to 26 cm. The activity versus depth for ^{241}Am has a less well-resolved peak at ~14-16 cm that almost certainly records the 1963/4 fallout maximum from the atmospheric testing of nuclear weapons.

Core Chronology

The ^{210}Pb chronology was calculated using the CRS and CIC dating models. The CRS model places the 1964 depth at about 19 cm which is deeper than the peak in ^{241}Am activities (Appendix 1). However, the CIC model places the 1964 depth at 14 cm, which is in good agreement with the depth suggested by the ^{241}Am record. This indicates that the use of the CIC model is more valid than the CRS model for this core. The ^{210}Pb calculations using the CIC model suggest that sedimentation rates in the top 29 cm of the core have three phases: constant rates from 29 to 20 cm of ~0.185 g cm^{-2} yr^{-1}, followed by a decline from 20-9 cm, and constant sedimentation rates of ~ 0.103 g cm^{-2} yr^{-1} in the upper 9 cm (Table 12).

Table 12 PHUI1 Chronology

Loch a Phuill CIC Model Pb-210 Chronology								
Core PHUI1								
Code 1	Date 2006							
90% Equilibrium depth = 25.4 cm, or 8.42 g/cm^2								
99% Equilibrium depth = 32.5 cm, or 13.17 g/cm^2								
Mean accumulation rate = 0.13762 ± 0.02235 g/cm^2/yr								
Depth	Drymass	Unsupp Pb-210	Chronology			Sedimentation Rate		
		Conc	Date	Age	Std			
cm	g/cm^2	Bq/kg	AD	Yr	Error	g/cm^2/yr	cm/yr	±
0	0	245.7	2006	0				
1	0.0698	247.3	2005	1	1	0.1027	0.938	25.9
2	0.1891	221.1	2004	2	1	0.1027	0.836	25.9
3	0.3085	197.7	2002	4	2	0.1027	0.733	25.9
4	0.4279	176.7	2001	5	3	0.1027	0.631	25.9
5	0.5472	158	1999	7	4	0.1027	0.528	25.9
6	0.8085	138.3	1996	10	4	0.1027	0.483	25.9
7	1.0698	121.1	1992	14	5	0.1027	0.438	25.9
8	1.3311	106	1989	17	5	0.1027	0.393	25.9
9	1.5924	92.8	1985	21	5	0.1027	0.347	25.9
10	1.9057	81.5	1981	25	5	0.1061	0.328	25.2
11	2.2711	71.7	1977	29	5	0.1131	0.333	23.9
12	2.6366	63	1973	33	6	0.12	0.338	22.6
13	3.002	55.4	1969	37	6	0.1269	0.344	21.3
14	3.3674	48.8	1964	42	6	0.1338	0.349	20
15	3.758	45.7	1960	46	6	0.1421	0.358	19.5

16	4.1738	45.5	1957	49	6	0.1516	0.37	19.7
17	4.5896	45.4	1953	53	6	0.1612	0.382	19.9
18	5.0054	45.2	1950	56	6	0.1708	0.394	20.1
19	5.4212	45.1	1946	60	6	0.1803	0.406	20.3
20	5.8671	42.3	1943	63	6	0.1851	0.407	20.4
21	6.3431	37.5	1940	66	6	0.1851	0.397	20.4
22	6.8191	33.2	1937	69	6	0.1851	0.387	20.4
23	7.2951	29.4	1935	71	6	0.1851	0.376	20.4
24	7.7711	26.1	1932	74	6	0.1851	0.366	20.4
25	8.2471	23.1	1929	77	6	0.1851	0.356	20.4
26	8.7885	21.2	1926	80	6	0.1851	0.34	20.4
27	9.3953	20.1	1923	83	7	0.1851	0.32	20.4
28	10.0021	19.1	1920	86	8	0.1851	0.3	20.4
29	10.6089	18.1	1917	89	9	0.1851	0.28	20.4

Biological analyses

Diatom analysis

The diatom screening exercise on PHUI1 revealed poor preservation and the presence of numerous broken valves (Table 13). The diatom assemblages were relatively species-rich and were comprised largely of non-planktonic, alkaline to slightly brackish taxa with only subtle changes in species composition throughout the core. In view of the preservation problems and inorganic nature of the sediments, no further analysis was carried out on this core.

Table 13 Results of the diatom screening on PHUI1

Loch	**a Phuill**	**Core PHUI1**		
Depth (cm)	Preservation notes	Species 20- 10%	Species 10-5%	Notes (↑ and ↓ relative to sample above)
Surface	Low conc. slide, some broken valves	Cocconeis neothumensis, Epithemia frickei, Fragilaria construens var venter	Fragilaria brevistriata, Fragilaria pinnata, Fragilaria vaucheriae, Cocconeis placentula var euglypta Amphora pediculus	**Others present:** Achnanthes clevei, Amphora pediculus, Gomphonema spp, Navicula tuscula, , Stephanodiscus spp.
3	Low conc. slide, some broken valves	Cocconeis neothumensis, Fragilaria construens var venter	Achnanthes clevei, Achnanthes minutissima, Epithemia frickei	**Decreases:** Epithemia frickei, Fragilaria brevistriata, **Increases:** Achnanthes clevei, Achnanthes minutissima, Cocconeis neothumensis,
8	Low conc. slide, some broken valves	Fragilaria brevistriata, Fragilaria construens var venter	Achnanthes clevei, Amphora pediculus, Cymbella gaeumannii, Cocconeis neothumensis	**Decreases:** Achnanthes minutissima, Cocconeis neothumensis, Epithemia frickei **Increases:** Cymbella spp., Fragilaria brevistriata, Gomphonema angustum, Mastogloia smithii
21	Low conc. slide, some broken valves	Fragilaria brevistriata, Fragilaria construens var venter	Achnanthes clevei, Achnanthes minutissima, , Amphora pediculus, Cocconeis neothumensis, Epithemia frickei, Mastogloia smithii	**Decreases:** Fragilaria brevistriata **Increases**: Epithemia frickei, Fragilaria construens var venter, Mastogloia smithii, Rhopalodia gibba
36	Low conc. slide, some broken valves	Fragilaria brevistriata, Fragilaria construens var venter, Fragilaria pinnata	Achnanthes minutissima, Cocconeis neothumensis	**Decreases:** Mastogloia smithii, Achnanthes clevei, Cocconeis neothumensis **Increases**: Fragilaria brevistriata,

				Fragilaria construens var venter, Fragilaria pinnata
43	Low conc. slide, some broken valves	Fragilaria brevistriata, Fragilaria construens var venter, Fragilaria pinnata, Achnanthes rosenstockii,	Achnanthes rosenstockii, Achnanthes clevei, Cocconeis neothumensis, Navicula jaernefeltii	**Decreases:** Achnanthes minutissima, Fragilaria brevistriata, Fragilaria construens var venter. **Increases:** Achnanthes rosenstockii, Navicula jaernefeltii, Nitzschia spp., Cocconeis neothumensis

Cladocera and macrofossil analyses

The Cladocera screening exercise on PHUI1 revealed very low abundance of remains in samples other than the surface (Table 14). Whilst it may be possible to concentrate the samples by using heavy liquid to separate out the sand, this would require further work. In view of this and the diatom preservation problems, it was recommended that no further cladoceran analysis would be carried out on this core. The core was not screened for plant macrofossils.

Table 14 Results of the Cladocera screening on PHUI1

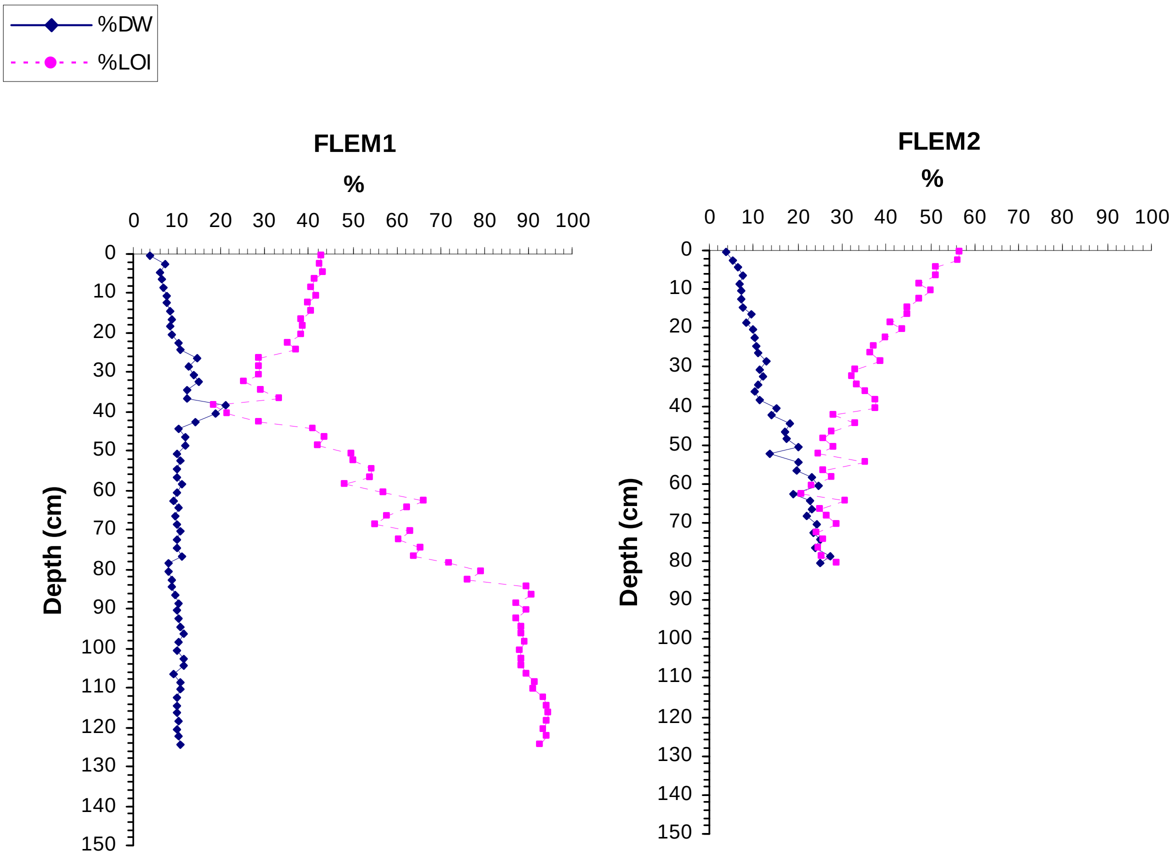
Loch	**Loch A Phuill**	**Core PHUI1**	
Depth (cm)	Dominant taxa	Sub-dominant taxa	Notes on sample
3	*Acroperus harpae* (25%)	*Chydorus sphaericus*	fine
21			remains too sparse for analysis
36			remains too sparse for analysis
43			remains too sparse for analysis

4. Loch Flemington

Core description

The open water core, FLEM1, was highly inorganic (~90% LOI) in the lower section below 85 cm (Figure 14). The %LOI decreased steadily to ~20% at 40 cm before increasing slightly again towards values of ~40% at the core top. The littoral core, FLEM2, was markedly different with a general increase in organic matter from ~30% at the base to ~50% at the core top.

Figure 14 Percentage dry weight and organic matter profiles of FLEM1 & FLEM2



Radiometric dating

Lead-210 Activity

Total ^{210}Pb activity reaches equilibrium with the supporting ^{226}Ra at a depth of ~40 cm in core FLEM1. In the section from 5 to 21 cm, unsupported ^{210}Pb activity declines more or less exponentially with depth from a maximum value of 165 ± 9 Bq kg^{-1}, suggesting relatively uniform sedimentation rates over the period of time spanned by this section. Sedimentation rates were different below and above the 5 to 21 cm section.

Artificial Fallout Radionuclides

The ^{137}Cs activity versus depth has a relatively well-resolved peak at a depth of 22.5 ± 2 cm recording the 1963 fallout maximum from the atmospheric testing of nuclear weapons.

Core Chronology

Chronological data were calculated using CRS and CIC dating models. The CRS model places the 1964 depth at about 23 cm, which is in good agreement with the depth suggested by the ^{137}Cs record. The CIC model places the 1964 depth at about 29 cm (Appendix 1). The results suggest that use of the CRS dating model is more suitable for this core. The ^{210}Pb calculations indicate that sedimentation rates gradually increased from the end of the nineteenth century to the 1960s, followed by a relatively constant period until the 1990s, and a further increase to the present day (Table 15).

Table 15 FLEM1 Chronology

Loch Flemington CRS Model Pb-210 Chronology								
Core FLEM	1							
Code 1	Date 29.01.2006							
210-Pb flux = 102.9 +/- 5.3 Bq/m^2/yr								
90% Equilibrium depth = 30.1 cm, or 2.84 g/cm^2								
99% Equilibrium depth = 35.6 cm, or 3.66 g/cm^2								
Depth	Drymass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	3305	2006	0				
2	0.129	3078.9	2004	2	2	0.0583	0.827	10.3
4	0.273	2841.2	2001	5	2	0.0537	0.742	9.2
6	0.4191	2610.4	1998	8	2	0.05	0.668	8.4
8	0.5717	2367.2	1995	11	2	0.0485	0.627	8.9
10	0.7242	2146.6	1992	14	2	0.0471	0.585	9.3
12	0.8919	1925.9	1989	17	2	0.0476	0.569	11.7
14	1.0648	1721.8	1985	21	2	0.0487	0.562	14.8
16	1.2403	1535.8	1981	25	2	0.0491	0.547	17.2
18	1.4238	1360.7	1977	29	3	0.0472	0.513	17.7
20	1.6073	1205.5	1974	32	3	0.0452	0.478	18.3
22	1.81	1017	1968	38	3	0.0317	0.303	22.4
24	2.0348	806.5	1961	45	4	0.0292	0.244	23.5
26	2.2751	619.2	1952	54	5	0.0301	0.233	23.9
28	2.5468	451.5	1942	64	6	0.0267	0.199	26.3
30	2.8186	329.2	1932	74	7	0.0233	0.164	28.8
32	3.1147	158.1	1908	98	8	0.0168	0.116	31.2
34	3.4191	66	1880	126	9	0.0093	0.062	33.6

Spheroidal carbonaceous particle analysis

The SCP profile from FLEM2 is considerably longer and peak SCP concentrations are approximately an order of magnitude higher than those in TANG2 and NGAD2 (Table 16, Figure 15). While the profile from FLEM2 would, therefore, appear to represent a considerably longer period of SCP accumulation, it is somewhat irregular suggesting frequent and considerable changes in sediment accumulation at the coring location. Hence it is very difficult to say whether the shape of the profile is due to changes in SCP deposition from the atmosphere (a requirement for the use of SCPs as a dating tool), or to changes in sedimentological factors at the coring location or, as seems most likely, a combination of the two. Due to this uncertainty, any chronological information obtained from the profile must be treated with caution.

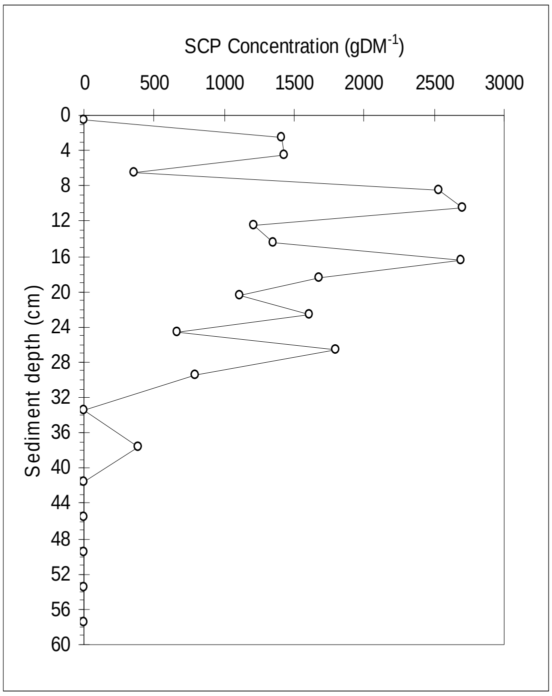
The SCP profile for FLEM2 appears to show two concentration peaks of similar magnitude at 10-11 cm and 16-17 cm. We can assume that either of these peaks are the SCP peak usually observed in Scotland in 1978. If we select the upper peak then 10-11 cm is dated to 1978 ± 5 and the mean sediment accumulation rate for the uppermost 10.5 cm is 0.375 cm yr^{-1}. If we select the lower peak then 16-17 cm is dated to 1978 ± 5 and the mean sediment accumulation rate for the uppermost 16.5 cm is 0.589 cm yr^{-1}. If we extrapolate both of these rates (i.e. we assume that the mean sediment accumulation rate continues back in time) then 1950 ± 15 would occur at 21 cm or 33 cm, respectively. It can be observed from the SCP concentration profile that the latter corresponds to a decline in SCP concentration below which SCP concentrations are low or zero.

While the assumption of a steady mean sediment accumulation rate over the last 50 years may appear reasonable, and would fit with the SCP concentration data, the SCP profile is highly irregular suggesting considerable variability in sediment accumulation over the period covered by the SCP record. Furthermore, it does not explain why there is a SCP concentration peak at 10-11 cm which, if the mean sedimentation rate is to be believed, would occur at ~1988. Finally, it is also possible that 10-11 cm represents 1978 ± 5 and 33 cm represents 1950 ± 15. This scenario suggests a decline in mean sediment accumulation rate from ~0.8 cm yr^{-1} for the period 1950-1978 to ~0.375 cm yr^{-1} for the period 1978-2006. It is not possible from the available data to indicate which of these scenarios is more likely to be correct and we can only be certain in the assumption that sediments above 37 cm are more recent than 1850.

Table 16 FLEM2: SCP concentrations

Sediment depth (cm)	SCP concentration (gDM^{-1})	± 90% confidence limit (gDM^{-1})
0 – 1	0	0
2 – 3	1406	689
5 - 6	1434	628
6 – 7	359	352
8 – 9	2529	1012
10 – 11	2703	1529
12 – 13	1216	688
14 – 15	1351	662
16 – 17	2697	999
18 – 19	1680	823
20 – 21	1117	547
22 – 23	1605	787
24 – 25	667	462
26 – 27	1801	789
29 – 30	797	553
33 – 34	0	0
37 – 38	392	384
41 – 42	0	0
45 – 46	0	0
49 – 50	0	0
53 – 54	0	0
57 - 58	0	0

Figure 15 FLEM2: SCP concentration profile



Biological analyses

Diatom analysis

Twelve samples were analysed for diatoms in the FLEM1 core (Table 17). A total of 118 diatom taxa were observed throughout the core although the individual samples were not particularly diverse with fewer than 50 taxa in all samples. The results for the major taxa are shown in Figure 16. The core was dominated throughout by non-planktonic taxa, particularly the benthic *Fragilaria* taxa (e.g. *Fragilaria construens* var. *venter, Fragilaria pinnata, Fragilaria brevistriata*). The only planktonic species of note was *Stephanodiscus parvus* which was present in low percentages (<5%) throughout the core. The assemblages are typical of circumneutral to alkaline, shallow, moderately productive waters. There were only minor changes during the period represented by the core with two major zones identified by the cluster analysis: Zone 1 from the core base to ~30 cm (pre-1900s to ~1930) and Zone 2 from ~30 cm to the surface (~1930 to present). Whilst *Fragilaria construens* var *venter* dominated in both zones there was an increase in this taxon in Zone 2 along with *Fragilaria exigua* and *Fragilaria capucina* var *mesolepta* relative to *Achnanthes minutissima*, *Cocconeis placentula* and *Fragilaria brevistriata*. *Achnanthes minutissima* and *Cocconeis placentula* are often associated with plant substrates whilst *Fragilaria* spp are rather cosmopolitan but typically attach themselves to mud surfaces. The observed shifts could, therefore, signify a slight loss in plant cover. The PCA axis 1 scores suggest that on the whole the changes have occurred gradually and they agree with the cluster analysis that the greatest compositional change occurred at ~1930. The subtle shifts are reflected by the low SCD scores which are all below 0.45 indicating only minor change from reference conditions.

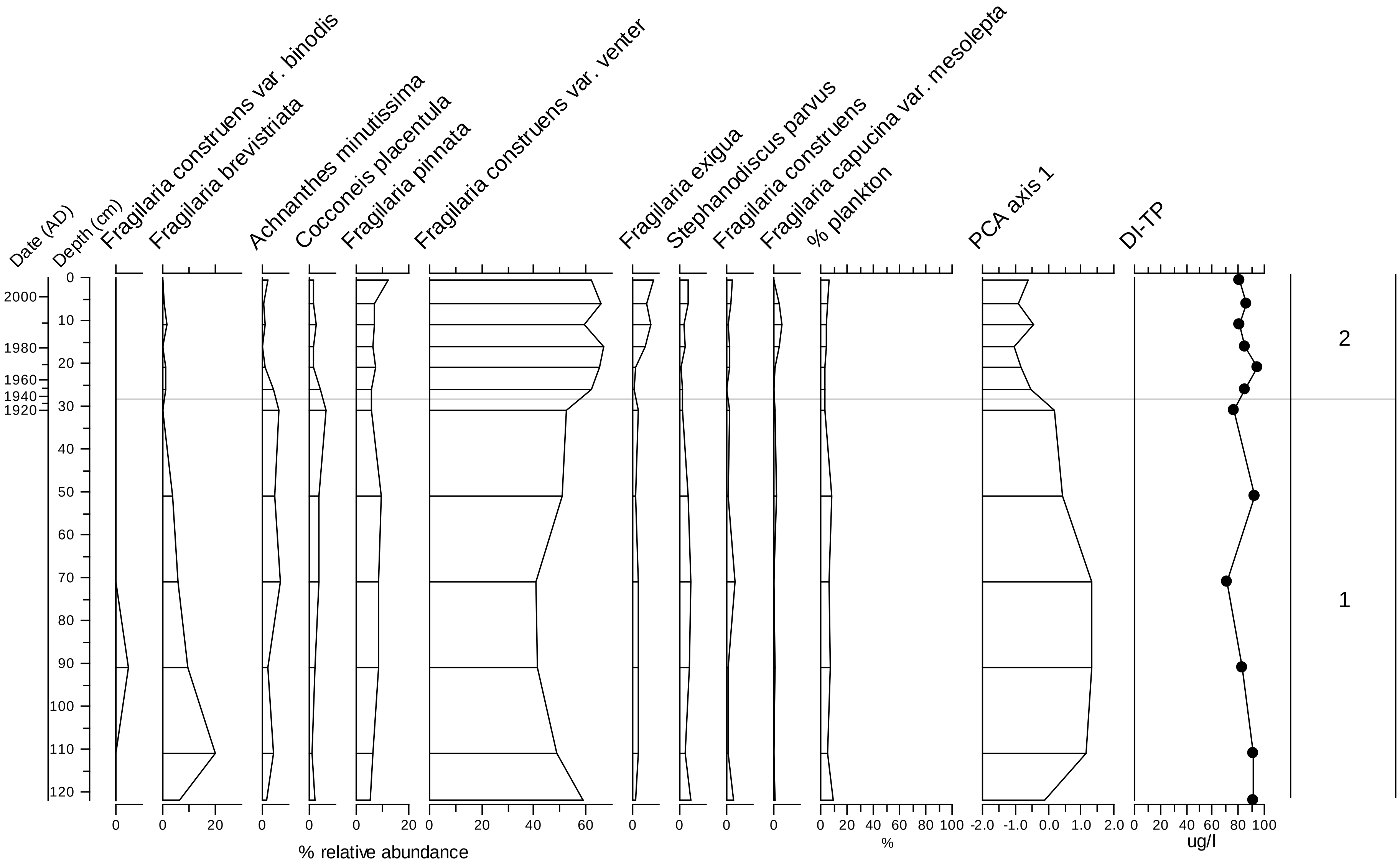
The DI-TP results suggest that there have been no marked changes in TP concentrations with relatively stable inferred values of ~70-95 µg l^{-1} throughout the core. The DI-TP concentrations are somewhat higher than the mean TP of 45 µg l^{-1} measured by SEPA for the period January 2005-June 2006, based on monthly values. The over-estimation by the model is most likely due to the dominance of benthic *Fragilaria* taxa in the core. These taxa are poor indicators of TP and are present even at high TP concentrations in the training set.

In summary, the diatom assemblages exhibit minor changes possibly associated with plant loss since ~1930 but there is no evidence of marked enrichment.

Table 17 Results of the diatom analysis on FLEM1

Depth (cm)	No taxa	N2	DI-TP µg l^{-1}	SCD	PCA axis 1 scores
1	27	2.49	80.5	0.32	-0.6122
6	37	2.52	86.6	0.27	-0.8948
11	43	3.24	81.0	0.32	-0.4379
16	40	2.80	84.8	0.31	-1.0172
21	47	3.07	94.5	0.32	-0.8091
26	46	3.45	84.7	0.37	-0.5087
31	46	4.43	76.3	0.44	0.1752
51	44	4.25	92.7	0.29	0.433
71	42	4.22	71.7	0.36	1.3084
91	48	3.56	83.0	0.40	1.3329
111	33	2.93	91.5	0.31	1.1517
122	41	2.67	91.7	0.00	-0.1213

Figure 16 Summary diatom diagram of FLEM1



Cladocera analysis

The Cladocera screening exercise on FLEM1 revealed very low abundance of remains in samples other than the surface (Table 18). On this basis, no further analysis was carried out.

Table 18 Results of the Cladocera screening on FLEM1

Loch Depth (cm)	**Flemington** Dominant taxa	**Core FLEM1** Sub-dominant taxa	Notes on sample
3	*Chydorus sphaericus* (38%)	*Bosmina longisrostris*	few remains, just countable
11	*Chydorus sphaericus* (37%)	*Alona affinis*	remains more sparse
31	*Chydorus sphaericus*	*Daphnia hyalina*	few remains
91			Too few remains for reliable results

Macrofossil analysis

The macrofossil screening exercise on the littoral core FLEM2 revealed that macrofossil remains were relatively abundant and full macrofossil analysis of 12 samples was carried out (Table 19).

Plant macrofossils

Three major zones were identified in the plant macrofossil assemblages by the cluster analysis (Figure 17):

Zone 1 (pre-~1850 AD, 60 and 52 cm)

Macrofossil remains in the lower section of this core were relatively sparse. The lowermost sample had large abundances of *Nitella* oospores but this declined by 52 cm and remained low throughout the rest of the core. Other species present within this zone were *Myriophyllum alterniflorum*, *Callitriche* spp, *Ranunculus* spp., *Potamogeton* cf *praelongus* and *Potamogeton obtusifolius*.

Zone 2 (~1850 and post 1850, 40 - 16 cm)

Species diversity increased within this zone relative to Zone 1 with increases in *Chara* oospores, *Ranunculus* spp and several *Potamogeton* species. *Isoetes lacustris* remains were present at 35 cm but did not occur in any of the other core samples. *Myriophyllum alterniflorum* occurred at 40 cm but it was not present in the samples above this level*.* *Najas flexilis* first occurred within FLEM2 at 35 cm (i.e. post ~1850 AD) in the form of spines with *Najas flexilis* seeds first being recorded within the core at 21 cm. These changes are reflected in the PCA scores which rise at the bottom of Zone 2.

Zone 3 (post ~1850, 10 - 1 cm)

Species diversity was also low in the uppermost section of the core. *Potamogeton* leaf fragments were evident but no *Potamogeton* seeds were found within this zone. *Nymphaeaceae trychosclereids* remains were found at 9 cm*.* *Najas flexilis* leaf spines were present throughout the zone and reached maximum abundances at 5 cm. PCA scores were generally lower after 26 cm, suggesting a general change in macrophyte community species between the bottom and the top of the core.

Zooplankton ephippia

For zooplankton ephippia, the core has been divided into two sections for descriptive purposes and the results are shown in Figure 18.

Pre-~1850 (60-40 cm)
The lowermost sample (60 cm) was dominated by *Daphnia hyalina* agg, *Chydorid* spp and, to a lesser extent, *Simocephalus* spp. These species decreased at 52 cm accompanied by an increase in *Ceriodaphnia* spp. The *Ceriodaphnia* spp rise was short lived, however, and the sample at 40 cm was similar to the lowermost sample.

Post-~ 1850 (35-0 cm)
The sample at 35 cm was dominated by *Daphnia hyalina* agg and *Chydorid* spp, but ephippia remains were sparse in the samples at 30 cm and 26 cm. At 21 cm *Daphnia hyalina* agg increased but subsequently declined towards the surface of the core. The *Chydorid* spp increased at 21 cm and remained abundant throughout the post-~1850 AD period. *Ceriodaphnia* spp occurred again at 15 cm and remained present throughout the upper section of the core. *Leydigia* spp occurred in the subsurface (1 cm) sample only. *Simocephalus* spp declined to minimal levels after ~1850 AD and were absent from the upper three samples.

Table 19 Results of the plant macrofossil analysis on FLEM2

Depth (cm)	No taxa	N2	PCA axis 1 scores
1	3	1.44	-0.5899
5	3	1.54	-0.8127
9	6	1.01	-0.88
16	7	1.04	-0.0924
19	9	1.14	-0.3378
21	6	1.32	-0.383
26	6	1.71	-0.8882
30	6	1.36	-0.2838
35	9	1.76	1.2448
40	10	3.72	2.7237
52	5	2.10	0.3307
60	5	1.22	-0.0315

Figure 17 Summary plant macrofossil diagram for FLEM2

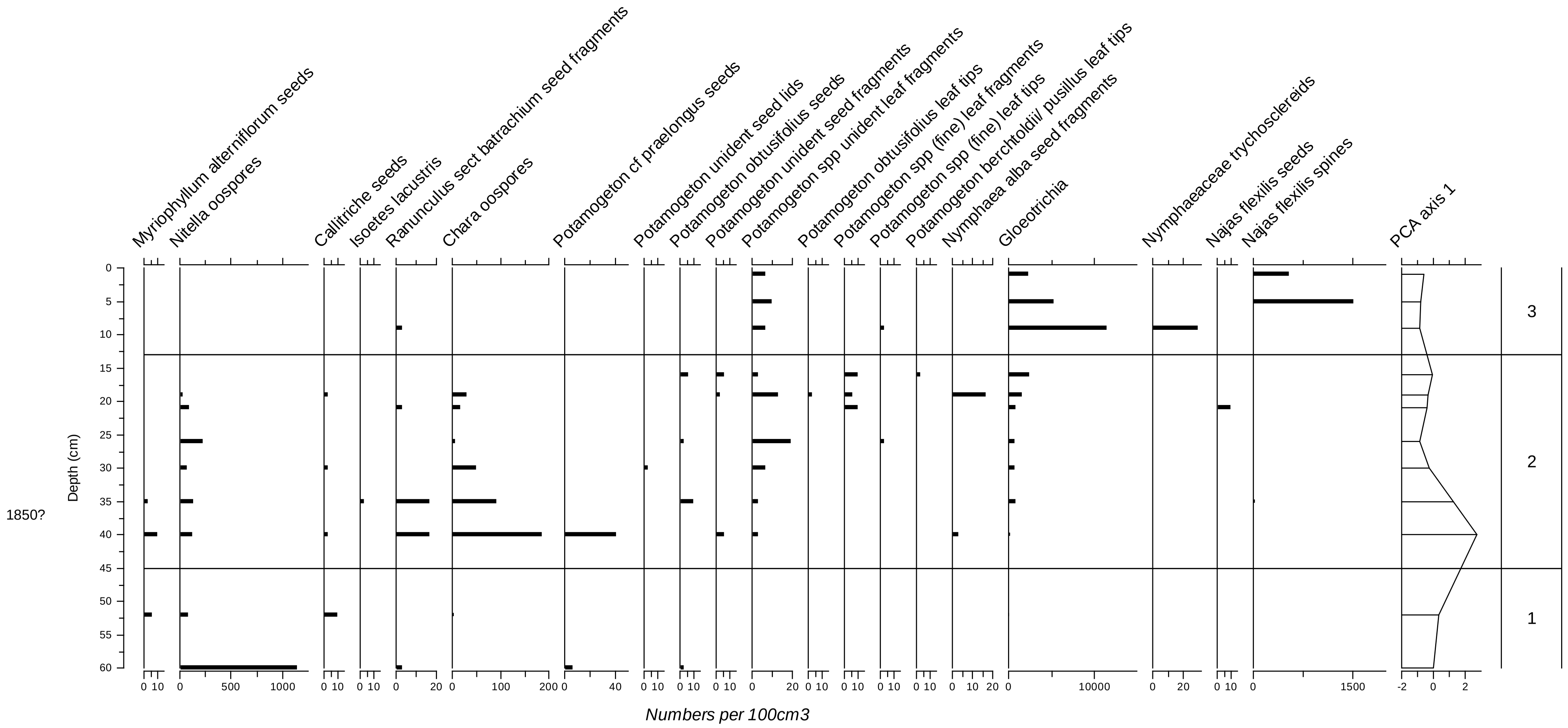
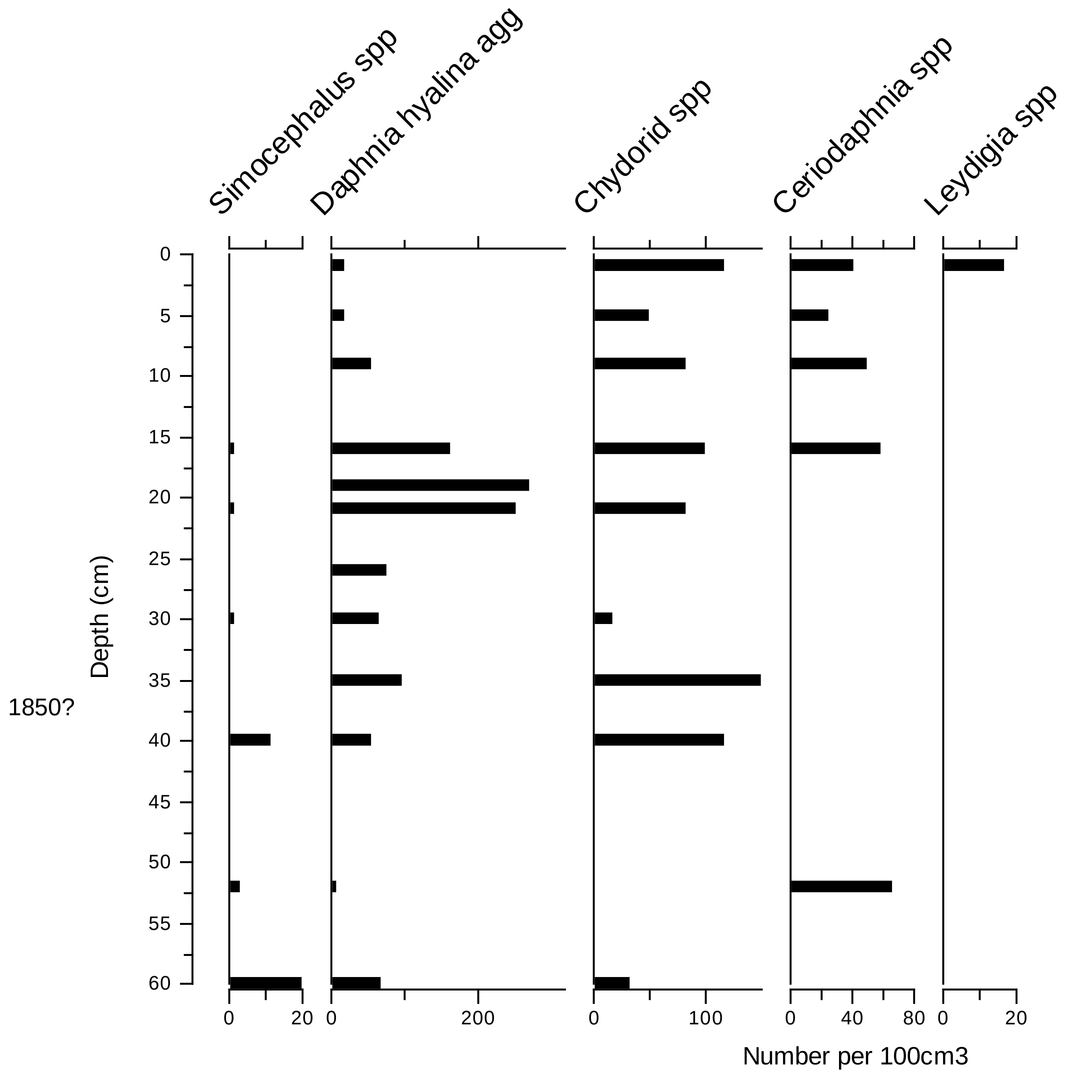


Figure 18 Summary zooplankton ephippia diagram for FLEM2



Discussion

The palaeoecological data demonstrate that Loch Flemington formerly supported a diverse plant community typical of a mesotrophic loch, comprised of *Nitella, Myriophyllum alterniflorum, Callitriche, Ranunculus*, *Potamogeton praelongus* and *P. obtusifolius*. *Nitella* oospores were present in extremely high numbers in the basal sample suggesting that it was very abundant in the past (Zhao *et al.*, 2006). However, in contrast to Lochs Tangy and Nan Gad, the lower core samples did not contain remains of *Lobelia* or *Isoetes*, indicating either that Loch Flemington was always more productive than the former lochs, or that the enrichment impacts date further back in time and our core was not of sufficient length to reach this period. The macrofossil record exhibits a marked change at ~1850 whereby *Myriophyllum alterniflorum* disappears, *Chara* becomes an important component of the flora, and *Najas flexilis* and several fine-leaved *Potamogeton* taxa first appear in the record. These shifts would suggest that the loch became more productive at this time (e.g. Sayer *et al*., 1999; Jeppesen *et al*., 2000; James *et al*., 2005). The macrofossil record exhibits marked changes in the upper section (above 10 cm) indicative of further enrichment with the loss of *Nitella, Chara* and a suite of other taxa (e.g. Blindlow, 1992), leaving only *Najas flexilis* and *Nymphaeaceae* and some unidentified *Potamogeton* leaf fragments. Owing to irregularities in the SCP profile is it not possible to identify the timing of these changes with any confidence.

Interestingly, the palaeo-record indicates that *Najas flexilis* has been present in the loch for at least 100 years or so and is still present today even though it is not identified as a biodiversity priority species for this loch and was not observed in a 2003 plant survey. *Potamogeton rutilis* is the priority species in Loch Flemington and was last recorded in 1975, being absent from Site Condition Monitoring surveys conducted in 2003 and 2004. Unfortunately, based only on leaf remains, this species cannot be distinguished from other fine-leaved *Potamogeton* taxa in the plant macrofossil record and, whilst seeds lend themselves to specific identification, they are quite uncommon in the palaeo-record (Davidson *et al*., 2005). Nonetheless the palaeo data suggest that the *Potamogeton* flora is impoverished in the most recent samples with fewer species present relative to the reference assemblages.

In contrast to the profound changes in the macrophyte community indicated by the macrofossil record, the diatom record was stable with dominance by non-planktonic *Fragilaria* taxa throughout the core. *Fragilaria* taxa are cosmopolitan and are commonly found in shallow lakes, often growing in situ on the surface sediments or attached to rock and plant surfaces. They can swamp the diatom assemblages in such lakes making it difficult to extract useful information regarding changes in water quality or to apply transfer functions to infer nutrient concentrations (e.g. Bennion *et al*., 2001). In Loch Flemington they tell us only that the light climate has remained favourable thus providing substrates on which the *Fragilaria* spp. can grow. There were small relative declines in the epiphytic taxa, *Achnanthes minutissima* and *Cocconeis placentula,* from ~1940 which suggests loss of plant biomass. In the absence of Cladocera analyses, the only zooplankton information is provided by the ephippia. The most notable features are the high numbers of *Daphnia hyalina* at ~20 cm which suggests higher planktonic production or possibly a fish kill which would have reduced grazing pressure on the zooplankton. The decline in *Simocephalus* since ~1850 is in agreement with the observed decline in the plant community as this is a plant obligate taxon and hence lower numbers indicate a decrease in plant abundance.

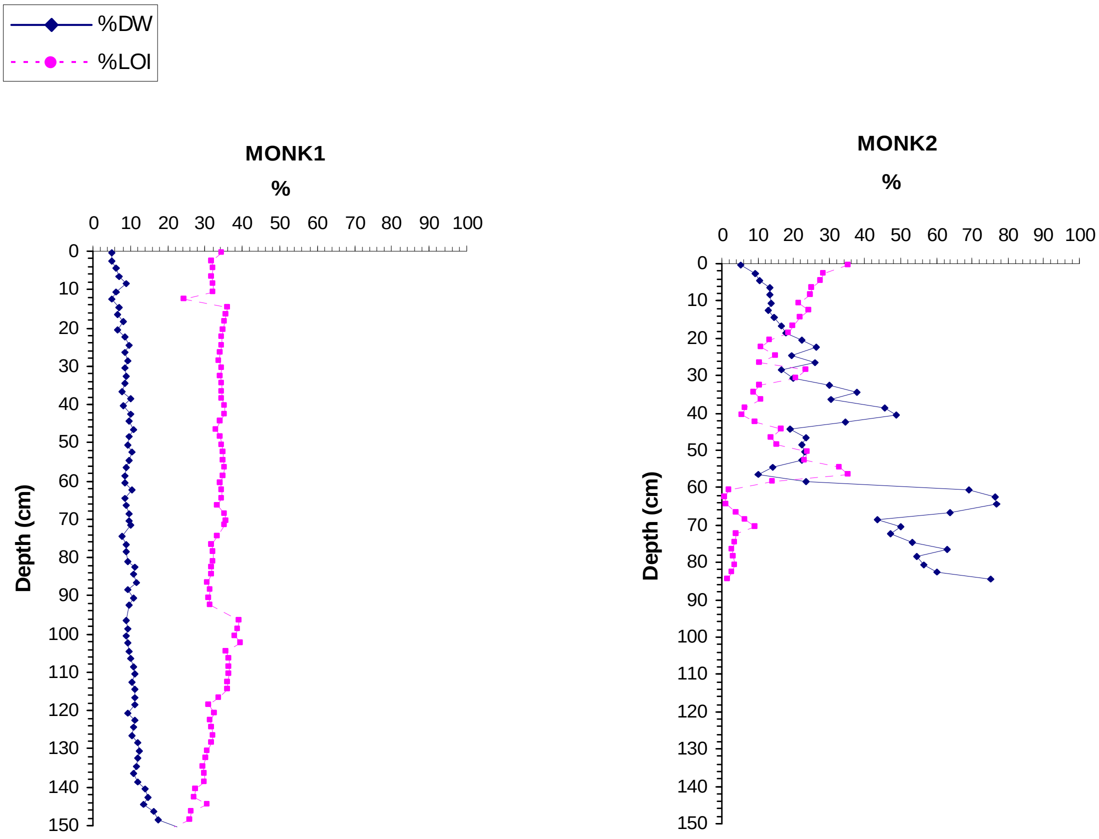
In summary, Loch Flemington has experienced complete turnover in its submerged macrophyte flora with presently no taxa in common with those observed in the reference assemblages. The loch was originally dominated by Charophytes, then underwent an initial phase of species shifts at around 1850 with a period of high diversity, before undergoing a further phase of enrichment resulting in a loss of plant diversity and marked compositional changes.

5. Monk Myre

Core description

The open water core, MONK1, was relatively organic throughout with %LOI values of 30-40% (Figure 19). The littoral core, MONK2, was markedly different with very inorganic sediments in the section below 60 cm (%LOI <10%), an organic layer from 50 to 60 cm, a decrease to relatively inorganic material at ~40 cm and a subsequent increase in organic matter to ~35% at the core top.

Figure 19 Percentage dry weight and organic matter profiles of MONK1 & MONK2



Radiometric dating

Lead-210 Activity

Total ^{210}Pb activity appears to reach equilibrium with the supporting ^{226}Ra at a depth of around 110-120 cm in core MONK1. The ^{226}Ra activities in the upper two measured samples are higher than those in the rest of the core, suggesting a change in sediment properties. In general, the unsupported ^{210}Pb profile is non-monotonic with the ^{210}Pb activities in some samples being lower than those in deeper samples, suggesting that sedimentation rates in this core are not stable and that dilution may have occurred.

Artificial Fallout Radionuclides

The ^{137}Cs activity versus depth has a relatively well-resolved peak at ~ 60-61 cm that almost certainly records the 1963 fallout maximum from the atmospheric testing of nuclear weapons. This is confirmed by a small peak in ^{241}Am at this depth.

Core Chronology

The ^{210}Pb chronology was calculated using the CRS dating model (Table 20) The CRS model places the 1964 depth at ~64 cm, in good agreement with the depth suggested by the ^{137}Cs and ^{241}Am records (Appendix 1). The ^{210}Pb calculations indicate that sedimentation rates in this core vary over time. In general, sedimentation rates increased from the 1910s to the 1970s. After a period of rapid sedimentation in the 1970s, the rates were back to the pre-1970s level, but have gradually increased again to the present time.

Table 20 MONK1 Chronology

Monk Myre Core MONK1 CRS Model Pb-210 Chronology							
210-Pb flux = 175.9 +/- 13.4 Bq/m^2/yr							
90% Equilibrium depth = 88.0 cm, or 7.92 g/cm^2							
99% Equilibrium depth = 109.0 cm, or 10.14 g/cm^2							
Depth	Drymass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
Cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	5649.3	2006	0				
2	0.1229	5508.8	2005	1	2	0.1648	2.592	15.7
4	0.25	5362.4	2004	2	2	0.1557	2.426	15.2
6	0.3772	5219.9	2003	3	2	0.1466	2.26	14.7
8	0.5044	5081.2	2003	3	2	0.1374	2.094	14.3
10	0.6315	4946.1	2002	4	2	0.1283	1.929	13.8
12	0.7683	4774.4	2001	5	2	0.1226	1.792	14.3
14	0.9083	4595.8	1999	7	2	0.1181	1.665	15.2
16	1.0483	4423.9	1998	8	2	0.1136	1.538	16.1
18	1.1883	4258.4	1997	9	2	0.1091	1.411	17
20	1.3283	4099.1	1996	10	2	0.1045	1.285	17.9
22	1.5059	3900.7	1994	12	2	0.1059	1.258	18.3
24	1.6961	3697.7	1992	14	3	0.1091	1.265	18.6
26	1.8862	3505.3	1991	15	3	0.1124	1.272	18.8
28	2.0764	3322.9	1989	17	3	0.1156	1.28	19.1
30	2.2666	3149.9	1987	19	3	0.1189	1.287	19.4
32	2.4498	3016.8	1986	20	4	0.1283	1.379	20.6
34	2.6307	2899.2	1985	21	4	0.1398	1.499	22.1

36	2.8117	2786.2	1983	23	4	0.1513	1.619	23.6
38	2.9926	2677.6	1982	24	4	0.1628	1.739	25.1
40	3.1765	2574.4	1981	25	4	0.1703	1.816	26.5
42	3.3692	2478.7	1980	26	5	0.1656	1.765	27.5
44	3.562	2386.6	1978	28	5	0.161	1.713	28.4
46	3.7547	2297.8	1977	29	5	0.1563	1.661	29.4
48	3.9475	2212.4	1976	30	5	0.1517	1.61	30.4
50	4.1402	2130.1	1975	31	6	0.147	1.558	31.4
52	4.3267	2035.7	1973	33	6	0.1388	1.472	32.1
54	4.5111	1940.6	1972	34	6	0.1293	1.375	32.7
56	4.6955	1850	1970	36	7	0.1198	1.278	33.3
58	4.8799	1763.6	1969	37	7	0.1104	1.181	33.9
60	5.0643	1681.2	1967	39	7	0.1009	1.083	34.6
62	5.2513	1592.1	1965	41	8	0.1001	1.063	36.7
64	5.4391	1504.4	1964	42	8	0.1021	1.067	39.5
66	5.6269	1421.5	1962	44	9	0.1041	1.072	42.2
68	5.8147	1343.1	1960	46	10	0.1061	1.077	44.9
70	6.0025	1269.1	1958	48	10	0.1081	1.081	47.6
72	6.2094	1168.6	1955	51	11	0.0996	0.988	49.9
74	6.4228	1066.8	1952	54	12	0.0876	0.863	52.1
76	6.6363	973.9	1950	56	14	0.0756	0.738	54.2
78	6.8497	889.1	1947	59	15	0.0636	0.613	56.4
80	7.063	811.7	1944	62	16	0.0516	0.487	58.5
82	7.2764	738	1941	65	18	0.0578	0.542	67.5
84	7.4898	670	1938	68	20	0.0699	0.658	78.8
86	7.7033	608.2	1934	72	22	0.082	0.773	90
88	7.9167	552.2	1931	75	24	0.0941	0.888	101.3
90	8.1301	501.3	1928	78	26	0.1063	1.004	112.6
92	8.3408	442.4	1924	82	27	0.0949	0.896	119.3
94	8.5507	386.7	1920	86	28	0.0756	0.714	124.5
96	8.7606	338	1916	90	30	0.0563	0.532	129.7
98	8.9705	295.4	1911	95	31	0.0371	0.35	134.9

Biological analyses

Diatom analysis

Twelve samples were analysed for diatoms in the MONK1 core (Table 21). A total of 116 diatom taxa were observed but the individual samples were not particularly diverse with only ~25-50 taxa per sample. The results for the major taxa are shown in Figure 20. The core was dominated throughout by non-planktonic taxa, particularly the benthic *Fragilaria* taxa (e.g. *Fragilaria brevistriata, Fragilaria construens, Fragilaria construens* var. *venter, Fragilaria pinnata*). However there were marked changes in the assemblages during the period represented by the core and three major zones were identified by cluster analysis: Zone 1 from the core base to ~110 cm (pre-1900), Zone 2 from ~110 to ~65 cm (~1900 to ~1960), and Zone 3 from ~65 cm to the surface (~1960 to present). Zone 1 was comprised of several non-planktonic taxa associated with relatively unproductive waters (e.g. *Achnanthes minutissima, Brachysira serians, Cymbella delicatula, Cymbella helvetica, Cymbella microcephala, Denticula kuetzingii*). These taxa decline slightly in Zone 2 whilst *Fragilaria brevistriata* increases, and in Zone 3 they decline still further or, in some cases, disappear. In contrast, *Fragilaria brevistriata* and *Fragilaria pinnata* increase in Zone 3, along with the planktonic diatom *Stephanodiscus parvus*. These shifts indicate enrichment of the loch from around 1960. The PCA axis 1 scores support the cluster analysis indicating a gradual shift in overall composition from the core base to ~65 cm (~1960) at which point an abrupt change occurs. The stable PCA axis 1 scores in the upper core reflect the low compositional change since 1960. The major shifts in the diatom assemblages are reflected by the high SCD scores of ~0.9-1.0 in the upper 60 cm of the core which indicate a significant shift from reference conditions (i.e. core bottom)..

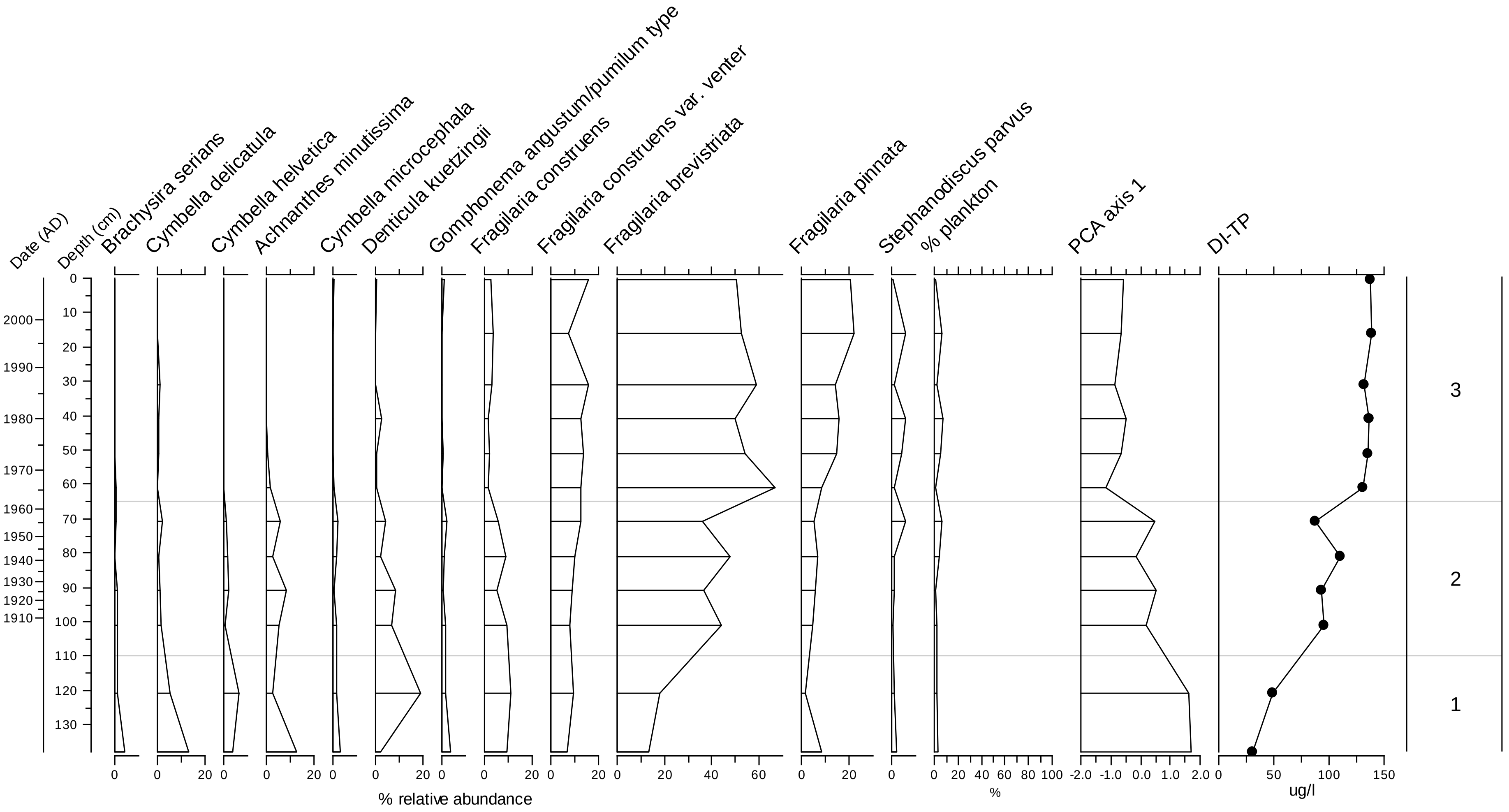
The DI-TP results support the ecological interpretation as inferred values increased markedly from less than 100 µg l^{-1} prior to ~1960 to in excess of 100 µg l^{-1} after that time. The DI-TP reconstruction also identifies an earlier phase of enrichment at ~110 cm (~1900), with baseline concentrations of < 50 µg l^{-1} experiencing approximately a doubling at this time. The current DI-TP concentration is considerably higher than the mean TP of 33 µg l^{-1} measured by SEPA for the period October 2005-June 2006, based on monthly values. The over-estimation by the model is most likely due to the dominance of benthic *Fragilaria* taxa in the core. These taxa are poor indicators of TP and are present even at high TP concentrations in the training set. Nevertheless, based on the shifts in the other taxa, one can still interpret the changes as being indicative of eutrophication.

In summary, the diatom assemblages exhibit changes indicative of two phases of enrichment: early eutrophication prior to 1900, followed by further enrichment in ~1960. There has been little change in the diatom assemblages over the last few decades.

Table 21 Results of the diatom analysis on MONK1

Depth (cm)	No taxa	N2	DI-TP µg l^{-1}	SCD	PCA axis 1 scores
1	25	3.14	137.28	0.97	-0.5745
16	26	3.75	138.98	0.96	-0.6381
31	28	3.53	131.50	0.95	-0.8721
41	30	4.30	136.77	0.93	-0.4646
51	35	3.83	135.23	0.90	-0.6564
61	28	3.08	130.85	0.92	-1.1485
71	50	4.38	87.86	0.52	0.4647
81	42	3.59	109.98	0.65	-0.1287
91	48	3.68	93.11	0.58	0.5087
101	38	3.26	94.94	0.56	0.1779
121	45	3.12	48.41	0.50	1.6145
138	41	2.85	31.04	0.00	1.7171

Figure 20 Summary diatom diagram of MONK1



Cladocera analysis

The Cladocera screening exercise on MONK1 revealed plentiful remains and full analysis of 12 samples was carried out, the results of which are shown in Figure 21. As with the diatom record, the cladoceran diversity was quite low (Table 22) with *Alona affinis* dominating in the lower part of the record and *Chydorus sphaericus* being the main species in the upper sediments. The basal sample contained few cladoceran remains and is, therefore, based on a low count and, as such, may not by fully representative. The low count also has an adverse effect on the SCD for this core.

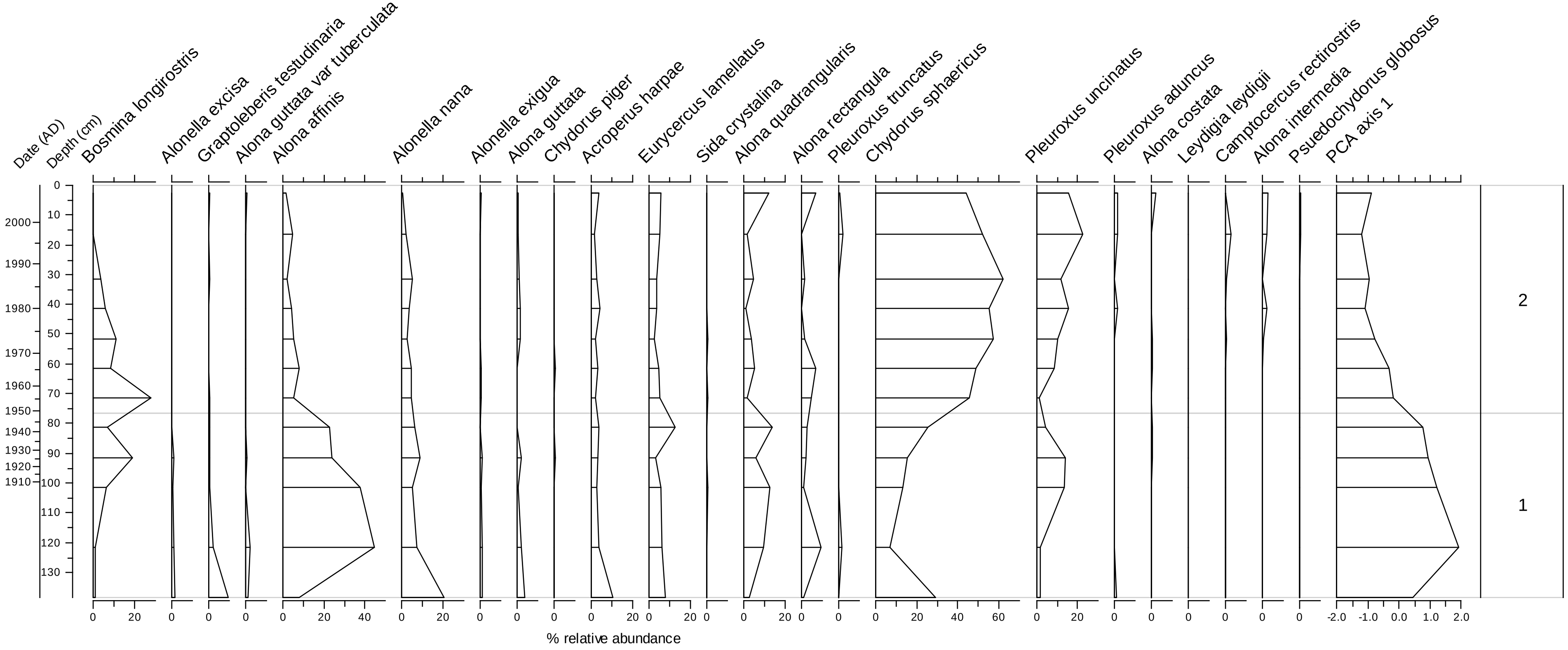
Zoning of the record with CONISS resulted in two zones. Throughout the lower Zone 1, *Alona affinis* was present in the greatest proportions but declined in importance towards the top of the zone. There was a concurrent increase in *Bosmina longirostris, Pleuroxus uncinatus* and *Chydorus sphaericus* over the same interval. The major shift in the species composition of MONK1 occurred at 76 cm (~1950 AD) and is shown by a sharp decline in PCA axis 1 scores, although this is a continuation of the gradual trends identified over Zone 1 (beginning in the early 1900s). *Alona affinis* declined to below 10% and was replaced by *Chydorus sphaericus* as the dominant species. During the early stages of Zone 2, abundance of *Bosmina longirostris* declined along with a simultaneous rise in *Pleuroxus uncinatus*. Over approximately the top 50 cm of the core the cladoceran assemblage remained relatively stable.

In summary, the cladoceran assemblage of MONK1 begins to change during the early 1900s with more marked shifts during the 1950s. From ~50 cm (~1970 AD) upwards, the cladoceran assemblage changes very little.

Table 22 Results of the Cladocera analysis on MONK1

Depth (cm)	No taxa	N2	SCD	PCA axis 1 scores
2.5	17	4.10	0.48	-0.8779
16.5	16	3.03	0.50	-1.1909
31.5	14	2.45	0.33	-0.957
41.5	14	2.95	0.41	-1.0777
51.5	14	2.82	0.43	-0.7789
61.5	12	3.69	0.37	-0.301
71.5	13	3.35	0.45	-0.1803
81.5	11	6.07	0.33	0.7721
91.5	16	6.75	0.38	0.9509
101.5	14	4.91	0.43	1.229
121.5	15	4.24	0.39	1.9424
138.5	16	6.13	0	0.4694

Figure 21 Summary Cladocera diagram for MONK1



Macrofossil analysis

Macrofossil analysis was not carried out at Monk Myre.

Discussion

The palaeoecological data indicate that Monk Myre formerly supported diatom and Cladocera communities typical of a mesotrophic loch but that these have both undergone changes associated with enrichment over the 150 years or so represented by the core, most notably during ~1950-1970. Whilst the diatom assemblages were dominated throughout by non-planktonic taxa, particularly the benthic *Fragilaria* taxa, they exhibit changes indicative of two phases of enrichment: i) early eutrophication prior to 1900 suggested by a shift from taxa associated with relatively unproductive waters (e.g. *Achnanthes minutissima, Brachysira serians, Cymbella delicatula, Cymbella helvetica, Cymbella microcephala, Denticula kuetzingii*) to *Fragilaria* spp., and ii) further enrichment occurring at ~1960 marked by the expansion of the planktonic, nutrient-tolerant species *Stephanodiscus parvus*, although plankton still comprise less than 10% of the total diatom assemblage. There has been little change in the diatom assemblages over the last few decades. The DI-TP results support the ecological interpretation as inferred values were low prior to ~1900 and then increased markedly to ~1960, since which time they have remained relatively stable. However, the current DI-TP concentration of ~100 µg l^{-1} is considerably higher than the measured mean TP of 33 µg l^{-1}. This over-estimation by the model is most likely due to the dominance of benthic *Fragilaria* taxa in the core which are poor indicators of TP and are present even at high TP concentrations in the training set (Bennion *et al*., 2001) Nevertheless, based on the shifts in the other taxa, one can still interpret the changes as being indicative of eutrophication.

The timing of the changes in the Cladocera assemblages are similar to those observed in the diatom record with initial declines in *Alona affinis* relative to *Pleuroxus uncinatus, Chydorus sphaericus* and the planktonic species *Bosmina longirostris* at ~1900, followed by more marked shifts during the 1950s when *Chydorus sphaericus* expands to become the dominant species and several other plant-associated taxa increase (e.g. *Camptocercus rectirostris, Alona intermedia, Pseudichydorus globosus*). This suggests an increase in plant biomass in the loch and availability of more niches for plant-associated cladocerans. However, the constant occurrence of *Eurycercus lamellatus* and *Acroperus harpae* indicates that plants were present throughout the period represented by the core. Similarly to the diatoms, the cladoceran assemblages change very little in the last few decades. In the absence of ephippia data it is not possible to interpret the zooplankton data further as information on the *Daphnia* is required to fully understand the dynamics of the zooplankton community.

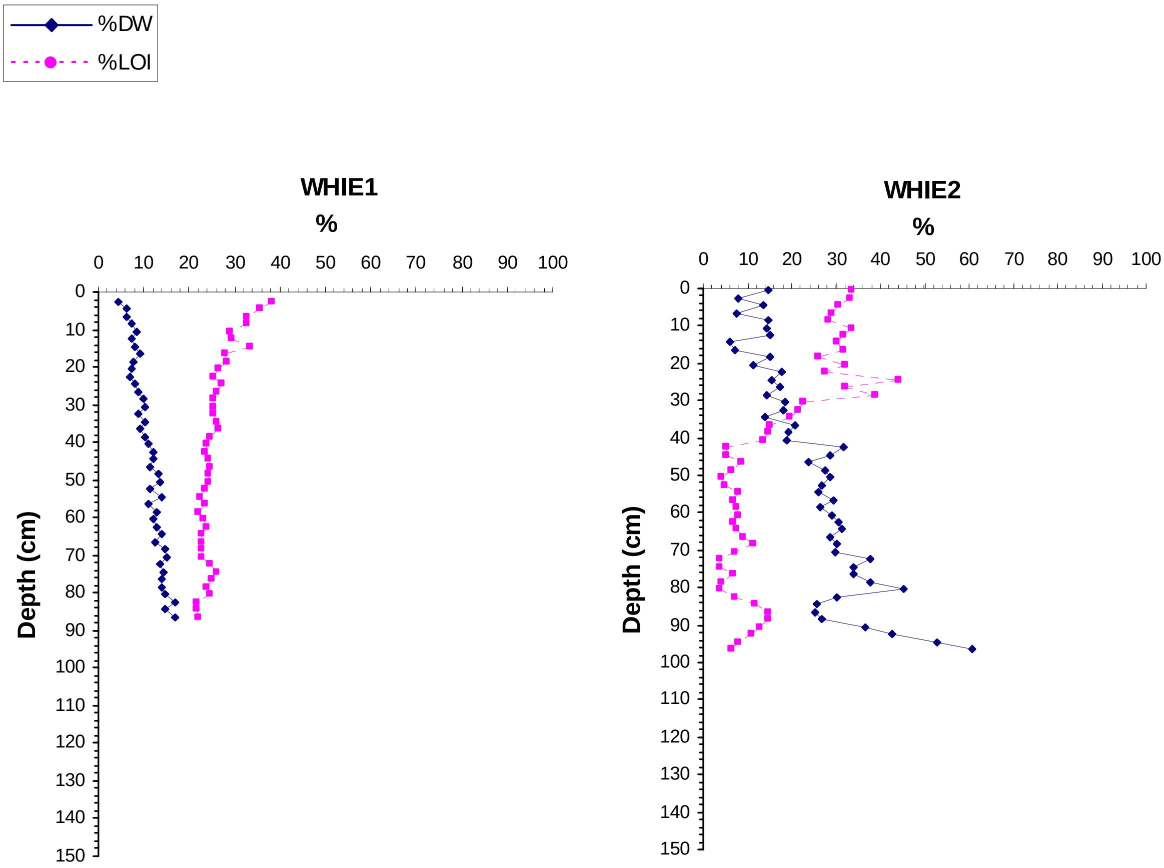
Macrofossil analysis was not undertaken on the Monk Myre core so it is not possible to say how the changes in water quality have impacted on the aquatic plant community. The largely benthic and plant-associated diatom and Cladocera assemblages in the upper core suggest that plants are still present in the loch. Nonetheless the marked shifts in these two groups suggest that the macrophyte flora is likely to have experienced some degree of change. *Najas flexilis*, the biodiversity priority species for Monk Myre, was last recorded in 1883 and was absent from a snorkel survey carried out in 1999 (Wingfield *et al*., 2004). If indeed this species has been lost from the site the palaeo-data suggest that enrichment during the twentieth century may be a likely explanation. In light of the findings, macrofossil analysis is recommended to assess changes in the aquatic plant community over the last century.

6. White Loch

Core description

The open water core, WHIE1, was relatively organic throughout with stable %LOI values of ~20-25% below 30 cm, gradually increasing to 38% at the core top (Figure 22). The littoral core, WHIE2, was different with inorganic sediments in the section below 40 cm (%LOI ~10%), a rapid increase in organic matter to a peak of ~40% at ~25 cm, and a subsequent decrease in organic matter to values of ~30% in the upper 25 cm of the core.

Figure 22 Percentage dry weight and organic matter profiles of WHIE1 & WHIE2



Radiometric dating

Lead-210 Activity

Total ^{210}Pb activity does not reach equilibrium with the supporting ^{226}Ra in core WHIE1. In general, unsupported ^{210}Pb activities, calculated by subtracting 226Ra activity from total ^{210}Pb activity, decline more or less exponentially with depth, suggesting that sedimentation rates in this core are relatively stable. The unsupported ^{210}Pb inventory (20470 Bq m^{-2}) is high, which indicates a mean ^{210}Pb supply rate of 637.4 +/- 30.4 Bq m^{-2} yr^{-1}. This is significantly higher than the estimated atmospheric flux, and suggests that the sedimentation processes may have been affected by a degree of sediment focusing in the coring location.

Artificial Fallout Radionuclides

The ^{137}Cs activity versus depth has a peak at ~50 cm, identifying the 1963 date of weapons fallout. This is confirmed by traces of ^{134}Cs also detected at ~50 cm. The 1986 Chernobyl accident is not recorded clearly in this core.

Core Chronology

The chronology was calculated using both the CRS and CIC dating models. The CRS model places the 1964 depth at ~52 cm, and the CIC model places the 1964 depth at ~54 cm, both in good agreement with the depth suggested by the ^{137}Cs record (Appendix 1). As unsupported ^{210}Pb activity in the 80.5 cm sample is less than the bottom sample, use of the CRS dating model is considered to be more suitable for this core (Table 23). Unsupported ^{210}Pb flux derived from the CRS model is two to three times higher than the average atmospheric flux in Scotland implying that the sediments have been affected by sediment focusing.

Table 23 WHIE1 Chronology

White Loch CRS Model Pb-210 Chronology								
Core WHIE1								
Code 1	Date	2006						
210-Pb flux = 637.4 +/- 30.4 Bq/m^2/yr								
90% Equilibrium depth = 76.0 cm, or 9.05 g/cm^2								
99% Equilibrium depth = 131.6 cm, or 18.04 g/cm^2								
Depth	Dry mass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	20470.9	2006	0				
3	0.1801	19633.3	2005	1	2	0.1389	2.039	8
6	0.393	18727.6	2003	3	2	0.1454	1.922	8
9	0.6349	17773.7	2001	5	2	0.1428	1.742	7.6
12	0.8934	16789	2000	6	2	0.1399	1.605	7.9
15	1.1684	15784.2	1998	8	2	0.1365	1.509	9
18	1.4401	14836	1996	10	2	0.1362	1.474	9.5
21	1.7138	13924.2	1994	12	2	0.1355	1.436	10
24	2.0005	12975.5	1991	15	2	0.1296	1.326	10.7
27	2.2871	12091.4	1989	17	2	0.1237	1.216	11.3
30	2.5738	11267.5	1987	19	2	0.1178	1.106	12
33	2.9231	10334.5	1984	22	2	0.1223	1.077	12.9
36	3.285	9448.8	1981	25	2	0.1289	1.064	13.9

39	3.6468	8638.9	1978	28	2	0.1355	1.052	14.8
42	4.0517	7833.7	1975	31	3	0.1332	1.007	15.7
45	4.4652	7091.8	1972	34	3	0.1292	0.955	16.6
48	4.8786	6420.2	1969	37	3	0.1252	0.904	17.5
51	5.2961	5783.4	1965	41	4	0.1203	0.848	18.5
54	5.7337	5082.1	1961	45	4	0.1107	0.772	19.9
57	6.1712	4465.8	1957	49	5	0.1011	0.697	21.2
60	6.6088	3924.3	1953	53	5	0.0914	0.621	22.6
63	7.0551	3436.1	1949	57	6	0.0988	0.66	25.7
66	7.5031	3006.4	1944	62	7	0.1095	0.721	29.1
69	7.9511	2630.5	1940	66	8	0.1202	0.782	32.6
72	8.4145	2329.7	1936	70	9	0.1293	0.827	36.3
75	8.8933	2088.4	1933	73	10	0.1366	0.854	40.4
78	9.3721	1872.2	1929	77	11	0.144	0.881	44.5
81	9.8587	1671.8	1926	80	12	0.1465	0.88	48.5
84	10.3846	1463.9	1921	85	14	0.1253	0.74	52
87	10.9105	1281.8	1917	89	15	0.1041	0.6	55.5

Biological analyses

Twelve samples were analysed for diatoms in the WHIE1 core (Table 24). A total of 133 diatom taxa were observed and the individual samples contained between 36 and 57 taxa. The results for the major taxa are shown in Figure 23. The core was comprised of both planktonic and non-planktonic taxa. There were considerably higher percentages of planktonic taxa in the White Loch core than in the cores from the lochs described above and this is due to the greater water depth. White Loch has a maximum water depth of ~11 m whilst the aforementioned lochs are all shallow with maximum water depths of less than 3 m.

There were marked changes in the assemblages during the period represented by the core with three zones identified by cluster analysis: Zone 1 from the core base to ~25 cm (~1920 to ~1980), Zone 2 from 35-12.5 cm (~1980-2000) and Zone 3 from 12.5 cm to the surface (2000-present). Zone 1 (pre-1980) was comprised of mostly non-planktonic taxa associated with relatively unproductive waters (e.g. *Cymbella helvetica, Cymbella microcephala, Denticula kuetzingii)* and the planktonic diatom *Cyclotella comensis*. These taxa decline substantially in Zone 2 whilst several taxa typically found in more mesotrophic conditions increase in relative abundance, namely *Cyclotella radiosa, Asterionella formosa* and *Fragilaria crotonesis*. These three species are all planktonic and have been observed as early indicators of enrichment in numerous lakes around the world. Another planktonic diatom, *Stephanodiscus parvus*, also increases in Zone 2 but notably expands further in Zone 3, indicating a second phase of enrichment to more eutrophic conditions since the late 1990s which appear to have prevailed for the last ten years, although this taxon has decreased again towards the very top of the core. The species shifts result in a marked increase in the planktonic component of the assemblage to ~60-70% in the upper part of the core. The changes are captured by the PCA axis 1 scores which increase most notably at ~35 cm and again at ~12 cm, marking the two phases of enrichment. There is a decline in the PCA axis 1 scores in the upper 2 cm which is driven by the decrease in *Stephanodiscus parvus* in the last few years. The SCD scores are relatively low below 35 cm reflecting little change from the core base prior to the mid-1970s but there is a significant increase to SCD scores in excess of 1.0 above this, indicating the marked shift in the diatom assemblages from reference condition since this time.

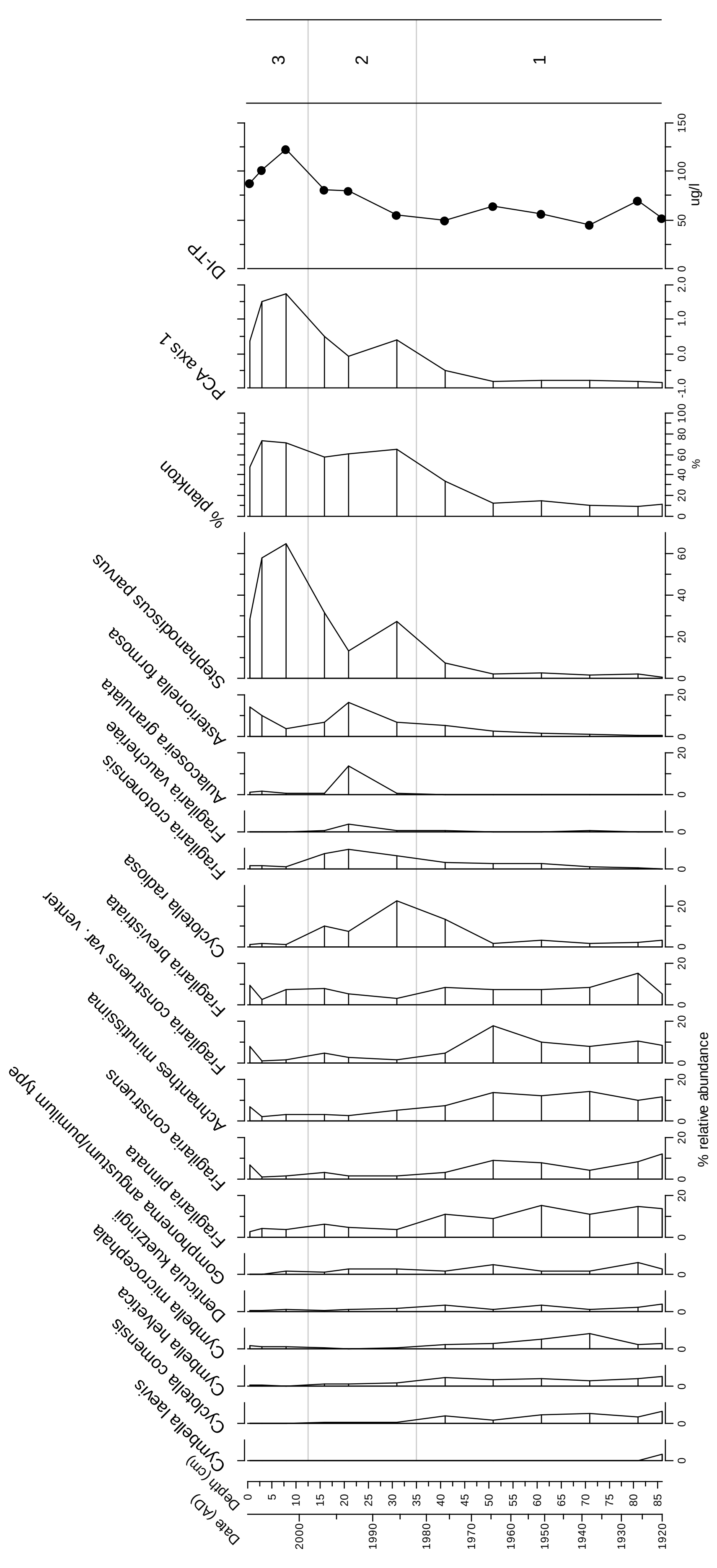
The DI-TP reconstruction suggests that TP concentrations in White Loch were relatively stable until the mid-1970s with values of ~40-60 µg l^{-1}. The DI-TP concentrations increased initially to ~90 µg l^{-1} and then further to a maximum of 135 µg l^{-1} in ~2000 before declining again to ~95 µg l^{-1} in the surface sample. Clearly the model is over-estimating TP concentrations in this loch as the measured mean TP based on SEPA data, collected on a monthly basis from November 2005 to June 2006, was only 28 µg l^{-1}. This is because the Northwest European training set contains many lakes with very high TP concentrations and it is in these sites that *Stephanodiscus parvus*, one of the dominant diatoms in the White Loch core, is found. Hence, this taxon has a high TP optimum in the model, resulting in high DI-TP values for samples in which this species is abundant. Nevertheless, whilst the actual values appear to be over-estimated for White Loch, there is no reason to believe that the inferred trend is unreliable.

In summary, the diatom assemblages exhibit an initial shift at ~1980 and a further change in ~2000 with a notable increase in planktonic forms, indicating two phases in the enrichment of the loch. There appears to have been a decline in the nutrient-tolerant taxa in the last few years but further analysis and monitoring would be required to determine whether this marks a sustained period of recovery.

Table 24 Results of the diatom analysis on WHIE1

Depth (cm)	No taxa	N2	DI-TP µg l^{-1}	SCD	PCA axis 1 scores
1	38	7.82	95.95	1.04	0.3694
3	39	3.02	115.6	1.39	1.5305
8	36	2.66	134.64	1.29	1.7481
16	44	8.24	88.86	0.97	0.5131
21	41	10.99	88.28	1.20	-0.0813
31	49	7.20	64.99	1.11	0.3937
41	54	8.66	48.08	0.51	-0.4766
51	54	6.69	62.01	0.41	-0.7981
61	52	5.86	51.39	0.32	-0.7695
71	57	5.17	38.40	0.39	-0.7772
81	43	4.43	60.95	0.22	-0.804
86	48	4.27	44.65	0.00	-0.848

Figure 23 Summary diatom diagram of WHIE1



Cladocera analysis

The Cladocera screening exercise on WHIE1 revealed relatively abundant remains and full analysis of 12 samples was carried out, the results of which are shown in Figure 24. The core was relatively rich in species with 26 taxa found. The number of species found in each sample declined towards the top of the core, although N2 values increased slightly due to the decline in dominance of individual species (Table 25). PCA axis 1 scores indicate a gradual shift in assemblage beginning from ~46 cm (~1970 AD). This is also shown by the SCD scores being greatest from 41.5 cm to the present day.

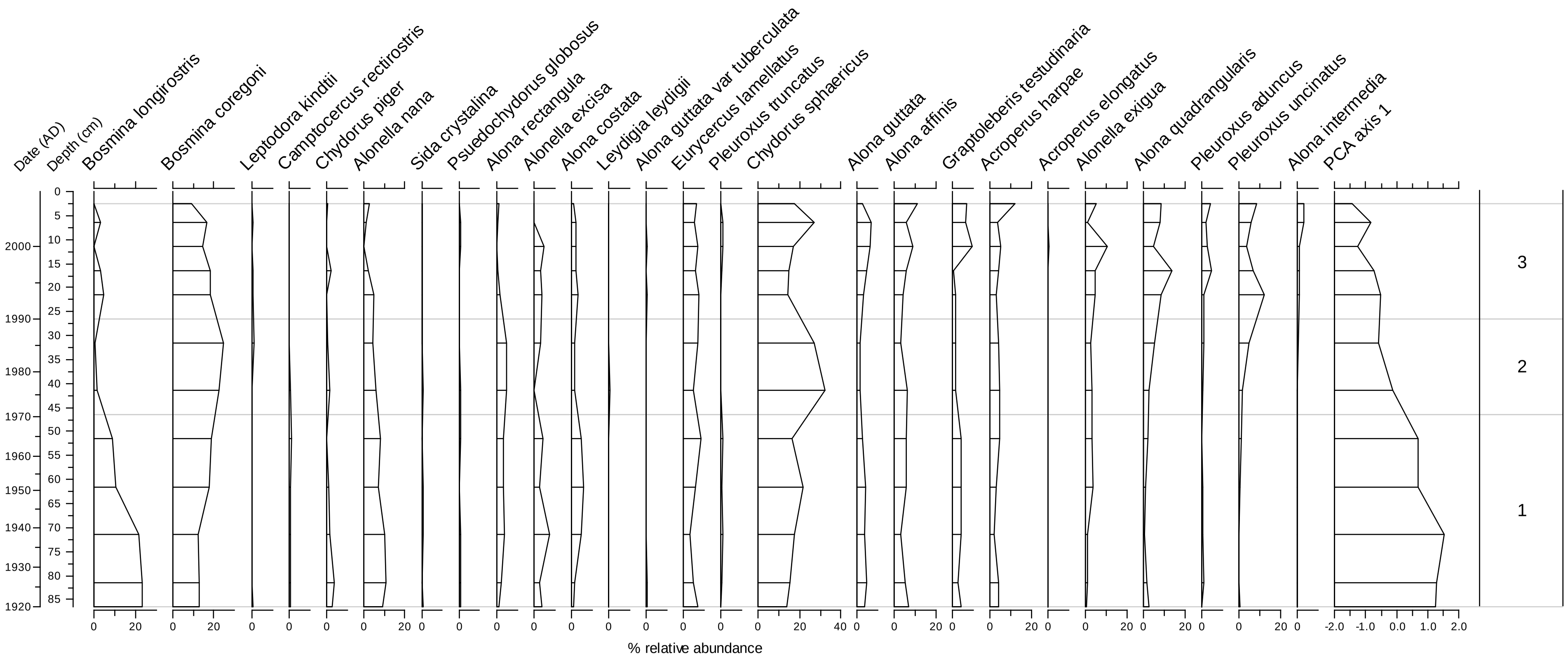
The diagram has been split into three zones using CONISS. The lower-most Zone 1 was marked by stable proportions of *Chydorus sphaericus*, *Bosmina coregoni* and *Alonella nana* amongst others. At the core base (dated to ~1920 AD), the dominant taxon was *Bosmina longirostris* (23%), which declined gradually to values less than 5% in Zones 2 and 3. Zone 2 begins at ~1970 AD (46 cm), with both *Chydorus sphaericus* and *Bosmina coregoni* recorded at over 20% throughout this period. By the top of Zone 2 at ~1990 AD (26 cm) there was a switch in the sub-dominant taxa with *Pleuroxus* species, *Alona quadrangularis, Alonella exigua, Alona guttata, Graptoleberis testudinaria* and *Acroperus harpae* all increasing while other *Alona* and *Alonella* species declined. This trend continued throughout Zone 3. Proportions of the dominant species at White Loch, *Bosmina coregoni* and *Chydorus sphaericus,* remained relatively stable towards the core top.

The greatest changes in SCD compared with the basal assemblage appear to be in the upper three or four samples, although SCD is shown to rise gradually towards the top of the core mirroring the continuing change at the site displayed in the PCA axis 1 scores.

Table 25 Results of the Cladocera analysis on WHIE1

Depth (cm)	No taxa	N2	SCD	PCA axis 1 scores
2.5	16	10.46	0.52	-1.4359
6.5	19	7.66	0.35	-0.8179
11.5	19	10.40	0.52	-1.2696
16.5	21	10.25	0.33	-0.7302
21.5	20	10.38	0.28	-0.5045
31.5	21	6.52	0.35	-0.5712
41.5	22	5.73	0.29	-0.1206
51.5	20	10.06	0.11	0.6737
61.5	21	8.93	0.11	0.7014
71.5	22	8.44	0.08	1.535
81.5	23	8.37	0.03	1.2937
86.5	23	8.55	0	1.2462

Figure 24 Summary Cladocera diagram for WHIE1



Macrofossil analysis

Macrofossil analysis was not carried out at White Loch.

Discussion

The palaeoecological data indicate that White Loch formerly supported a diverse, largely non-planktonic diatom community typical of a mesotrophic loch. However, the diatom flora has undergone changes associated with enrichment over the ~100 years represented by the core. There appear to be two phases with firstly a decline in taxa associated with relatively unproductive waters (e.g. *Cymbella helvetica, Cymbella microcephala, Denticula kuetzingii, Cyclotella comensis*) at ~1980 and a relative increase in several planktonic taxa typically found in more productive waters, namely *Cyclotella radiosa, Asterionella formosa* and *Fragilaria crotonesis* (Bennion *et al*., 2004). This was followed by a further change in the late 1990s with a notable increase in planktonic forms (comprising 60-70% of the total assemblage), particularly *Stephanodiscus parvus,* indicating a second phase of enrichment to more eutrophic conditions which appear to have prevailed for the last decade. The relative abundance of *Stephanodiscus parvus* decreases in the surface sample but this could be an artefact whereby the high sedimentation rate means that the upper 1 cm has not yet captured the full annual fallout of diatoms from the water column. Therefore further analysis and monitoring is required to determine whether this marks a sustained period of recovery. The DI-TP reconstruction supports the ecological interpretation suggesting that TP concentrations in White Loch were relatively stable until the mid-1970s and then increased throughout the 1980s and 1990s reaching a maximum in ~2000, before declining again in the surface sample. The model over-estimates TP concentrations in White Loch because the training set contains many lakes with very high TP concentrations and it is in these sites that *Stephanodiscus parvus*, one of the dominant diatoms in the White Loch core, is found. Nevertheless, there is no reason to believe that the inferred trend is unreliable.

The Cladocera assemblages of White Loch also experienced shifts over the period represented by the core. The timing of the changes was coincident with those in the diatom record. The assemblages in the lower part of the core were relatively stable being comprised of a diverse fauna including *Chydorus sphaericus*, *Bosmina coregoni, Alonella nana* and *Bosmina longirostris*, although the latter species starts to decline from ~1940. Subtle changes occur at ~1970 with a further decrease in *Bosmina longirostris* and increases in *Chydorus sphaericus* and *Bosmina coregoni*. It is difficult to interpret the changes in the *Bosmina* spp. as the observed decrease in *B. longirostris* could be related to an increase in *Daphnia* but ephippia are required to determine the relationships between the planktonic taxa. In the upper part of the core from ~1990 several plant-associated species increase (e.g. *Pleuroxus* spp, *Alona quadrangularis, Alonella exigua, Alona guttata, Graptoleberis testudinaria*, *Acroperus harpae*) suggesting an increase in plant biomass.

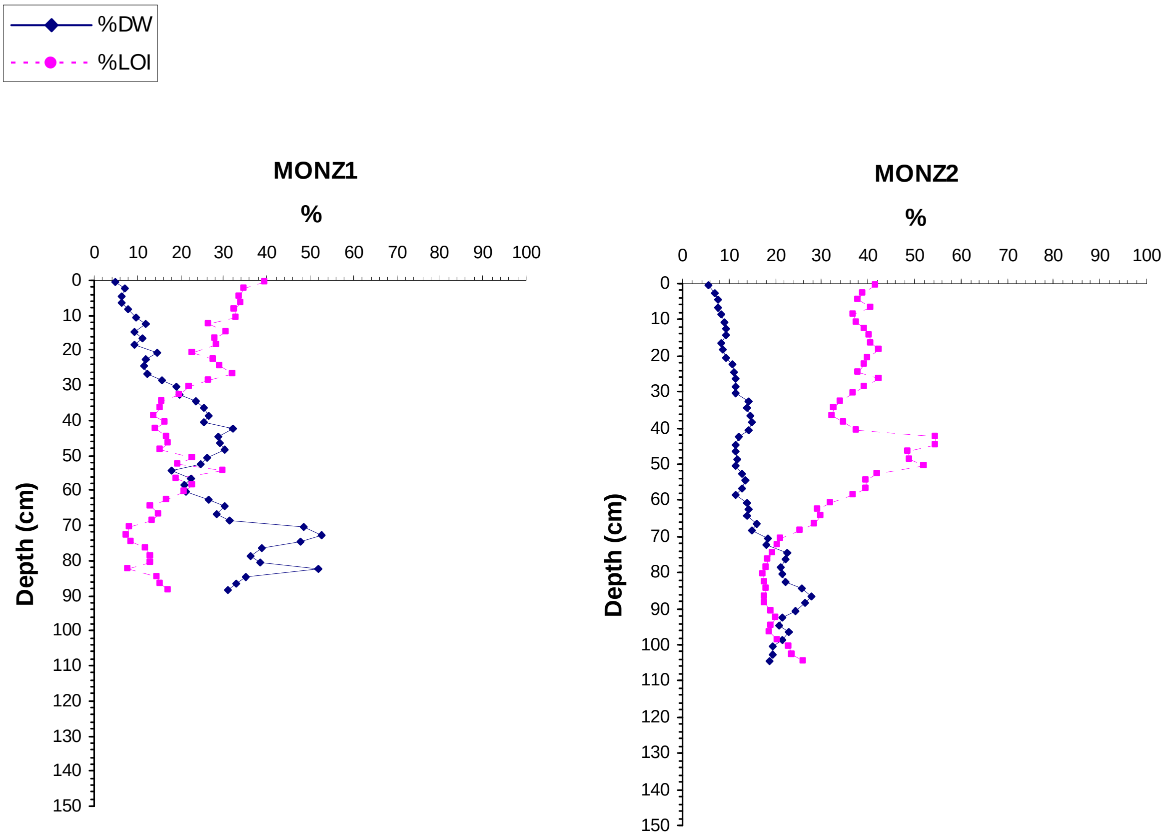
In summary, whilst the Cladocera assemblages indicate that plants have been abundant throughout the period represented by the core and that a diverse plant community is likely to be present today, the shifts may reflect a change in the species composition of the submerged macrophyte flora. The diatom data indicate that there have been two phases of enrichment (in ~1980 and the late 1990s) with a marked increase in the planktonic component of the diatom flora. *Najas flexilis*, the biodiversity priority species for White Loch, was last recorded in 1882 and was absent from a snorkel survey carried out in 1999 (Wingfield *et al*., 2004). If indeed this species has been lost from the loch, the palaeo data suggest that recent enrichment may be a possible explanation. In light of the findings and the occurrence of blue-green algal blooms on the loch over the last few years, macrofossil analysis is strongly recommended to assess changes in the aquatic plant community during the twentieth century, and particularly over the last few decades.

8. Loch Monzievaird

Core description

The two cores share a number of common features although these occur at different depths in MONZ1 than in MONZ2, presumably due to spatial variation in sediment accumulation rates (Figure 25). Both have low organic matter content at the core bottom which gradually increases to a peak and subsequently declines. This is followed by a further but smaller increase in organic content. The %LOI values are relatively stable at ~40% in the upper ~20cm, although there is an increasing trend in this section in the open water core which is not apparent in the littoral core.

Figure 25 Percentage dry weight and organic matter profiles of MONZ1 & MONZ2



Radiometric dating

Lead-210 Activity

Total ^{210}Pb activity reaches equilibrium with the supporting ^{226}Ra at a depth of more than 51 cm in core MONZ1. The exponential values of unsupported ^{210}Pb activities, calculated by subtracting 226Ra activity from total ^{210}Pb activity, decline with depth but the trends are non-linear suggesting that sedimentation rates in this core vary over time.

Artificial Fallout Radionuclides

The ^{137}Cs activity versus depth record has a well-resolved peak at ~19.5 cm that presumably records the 1963/4 fallout maximum from the atmospheric testing of nuclear weapons. This is confirmed by traces of ^{241}Am detected at this depth.

Core Chronology

The chronology was calculated using the CRS dating model (Table 26). The CRS model places the 1964 depth at ~20 cm, in good agreement with the depth suggested by the ^{137}Cs record (Appendix 1). However, the errors for the dates calculated using the CRS model below 25 cm increase and are relatively high, and therefore the earlier dates should be interpreted with caution. Sedimentation rates in this core were relatively stable in the first half of the twentieth century, followed by an increase to the beginning of the 1990s with peak values of ~0.06 g cm^{-2} yr^{-1}. In the last decade, the mean sedimentation rate value has decreased to ~0.047 g cm^{-2} yr^{-1}.

Table 26 MONZ1 Chronology

Monzievaird CRS Model Pb-210 Chronology								
Core MONZ1								
Code 1	Date 2006							
210-Pb flux = 162.9 +/- 8.8 Bq/m^2/yr								
90% Equilibrium depth = 26.3 cm, or 2.82 g/cm^2								
99% Equilibrium depth = 33.8 cm, or 4.37 g/cm^2								
Depth	Drymass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	5230.9	2006	0				
1	0.0554	5052.3	2005	1	2	0.0513	0.858	8.9
2	0.1148	4858.7	2004	2	2	0.0488	0.777	9.1
3	0.1742	4672.4	2002	4	2	0.0463	0.696	9.3
4	0.2336	4493.3	2001	5	2	0.0438	0.614	9.4
5	0.3062	4291.3	2000	6	2	0.0444	0.581	9.9
6	0.392	4070.2	1998	8	2	0.0483	0.595	10.6
7	0.4778	3860.5	1996	10	2	0.0521	0.61	11.3
8	0.5636	3661.6	1995	11	2	0.056	0.624	12
9	0.6494	3472.9	1993	13	2	0.0598	0.638	12.8
10	0.7442	3274.5	1991	15	2	0.0599	0.621	13.3
11	0.8481	3069.3	1989	17	2	0.0563	0.572	13.7
12	0.9519	2876.9	1987	19	2	0.0526	0.523	14
13	1.0557	2696.6	1985	21	2	0.049	0.474	14.4
14	1.1596	2527.6	1983	23	3	0.0454	0.425	14.7
15	1.2634	2369.2	1981	25	3	0.0417	0.376	15.1

16	1.3793	2180.5	1978	28	3	0.0398	0.345	16.1
17	1.5073	1970.6	1975	31	4	0.0395	0.33	17.7
18	1.6353	1780.8	1971	35	4	0.0392	0.316	19.3
19	1.7633	1609.4	1968	38	4	0.0389	0.301	21
20	1.8956	1434	1964	42	5	0.0369	0.277	22.6
21	2.0324	1259.7	1960	46	6	0.0331	0.243	24.3
22	2.1691	1106.7	1956	50	6	0.0294	0.209	26
23	2.3128	942.7	1951	55	8	0.0265	0.182	29.3
24	2.4635	778.7	1945	61	9	0.0245	0.162	34.1
25	2.6142	643.2	1939	67	11	0.0225	0.142	38.9
26	2.7745	519.2	1932	74	14	0.0217	0.13	42.9
27	2.9444	409.7	1924	82	18	0.0221	0.126	46
28	3.1144	323.2	1917	89	21	0.0226	0.122	49.2
29	3.2843	255	1909	97	25	0.023	0.118	52.3
30	3.4542	201.2	1901	105	29	0.0234	0.114	55.4

Spheroidal carbonaceous particle analysis

The SCP profile from MONZ2 is considerably longer and peak SCP concentrations are approximately an order of magnitude higher than those in TANG2 and NGAD2 (Table 27, Figure 26). As for FLEM2, the profile from MONZ2 would, therefore, appear to represent a considerably longer period of SCP accumulation. However it is somewhat irregular suggesting frequent and considerable changes in sediment accumulation at the coring location and, similarly to FLEM2, it is not possible to know whether the profile is due to changes in SCP deposition from the atmosphere, sedimentological changes at the coring location or a combination of the two. Due to this uncertainty, any chronological information obtained from the profile must be treated with caution.

Although the SCP profile for MONZ2 is irregular, it does exhibit a clear concentration peak. If we assume that this is the SCP peak usually observed in Scotland then 10-11 cm can be ascribed the date 1978 ± 5. This would provide a mean sediment accumulation rate for the uppermost 10.5 cm of 0.375 cm yr^{-1}. If this accumulation rate is extrapolated below this depth then 1950, the date of the rapid increase in concentration, should occur at ~21 cm. If this feature is represented in the MONZ2 SCP profile by the decline in concentration at 21-24 cm then this would appear to fit quite well. However, if this is indeed the case then it becomes difficult to explain the peak in SCP concentration below 24 cm where concentrations reach levels only exceeded by the SCP concentration peak in the upper core.

If, on the other hand, we assume that the lower decrease in SCP concentration at 34-36 cm represents ~1950, as is sometimes observed in areas of low deposition or rapidly accumulating sediments (i.e. the move from below to above the limit of detection equates to the rapid increase in SCP concentration), then the mean sediment accumulation rate for the upper 35 cm is ~0.625 cm yr^{-1}. Unless there has been a major change in sediment accumulation rate (as is quite possible in littoral areas) then this accumulation rate does not fit with the SCP concentration peak at 10–11 cm.

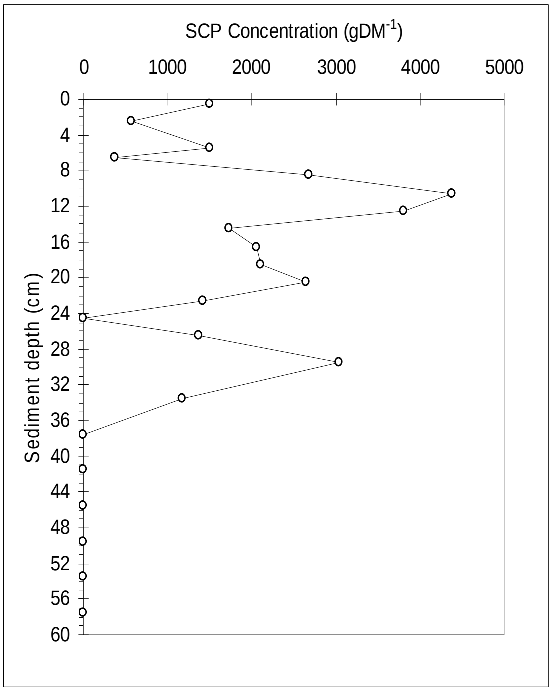
In summary, there are three possible chronological conclusions that may be drawn from the SCP profile from MONZ2. In order of decreasing certainty:

i) Sediments above 35 cm are more recent than 1850.
ii) 10-11 cm represents 1978 ± 5
iii) 21-24 cm represents 1950 ± 15

Table 27 MONZ2: SCP concentrations

Sediment depth (cm)	SCP concentration (gDM^{-1})	± 90% confidence limit (gDM^{-1})
0 – 1	1498	734
2 – 3	566	227
5 - 6	1500	848
6 – 7	380	373
8 – 9	2687	1178
10 – 11	4373	1189
12 – 13	3813	1321
14 – 15	1740	984
16 – 17	2059	1165
18 – 19	2102	1030
20 – 21	2640	1493
22 – 23	1415	801
24 – 25	0	0
26 – 27	1380	956
29 – 30	3043	1218
33 – 34	1184	820
37 – 38	0	0
41 – 42	0	0
45 – 46	0	0
49 – 50	0	0
53 – 54	0	0
57 - 58	0	0

Figure 26 MONZ2: SCP concentration profile



Biological analyses

Diatom analysis

Twelve samples were analysed for diatoms in the MONZ1 core (Table 28). A total of 139 diatom taxa were observed with between ~30 to 60 taxa occurring in the individual samples. The results for the major taxa are shown in Figure 27. The core was comprised of both planktonic and non-planktonic taxa. As for White Loch, there were considerably higher percentages of planktonic taxa in the Monzievaird core than in the cores from the shallow lochs owing to greater water depth. The depth of the open water from where the MONZ1 core was taken was ~9 m.

There were marked changes in the assemblages during the period represented by the core with three zones identified by cluster analysis: Zone 1 from the core base to ~28 cm (pre-1900 to ~1900), Zone 2 from ~28 to 15 cm (~1900-1980) and Zone 3 from 15 cm to the surface (~1980 to present). Zone 1 (pre-~1900) was comprised of taxa associated with relatively unproductive waters, particularly *Cyclotella* taxa (e.g. *Cyclotella comensis, Cyclotella pseudostelligera)* and *Achnanthes minutissima*. These taxa decline substantially in Zone 2 whilst several taxa typical of more productive conditions increase in relative abundance, namely *Asterionella formosa* and *Fragilaria crotonesis*. These two species appear in the White Loch core as indicators of enrichment in the mid-1970s although in Monzievaird their appearance is almost a century earlier. *Stephanodiscus parvus* also increases in Zone 2 but notably expands further in Zone 3 (from ~1980) along with *Fragilaria crotonensis* and *Aulacoseira* taxa. Consequently the percentage of planktonic taxa increases. These shifts indicate further enrichment to more eutrophic conditions which appear to have prevailed for the last few decades. The gradual but progressive change in the diatom assemblages throughout the sediment core are recorded by the PCA axis 1 scores which steadily decrease from ~40 cm to the 20 cm sample. The slightly more abrupt change at ~15 cm (Zone 2/3 boundary) is reflected in the increase in the PCA axis 1 scores at this point in the core. The SCD scores are low (~0.33) in the core section below 40 cm and then gradually increase to values of ~1.20 at the core top, reflecting the progressive deviation of the diatom assemblages from reference conditions (i.e. those at the bottom of the core).

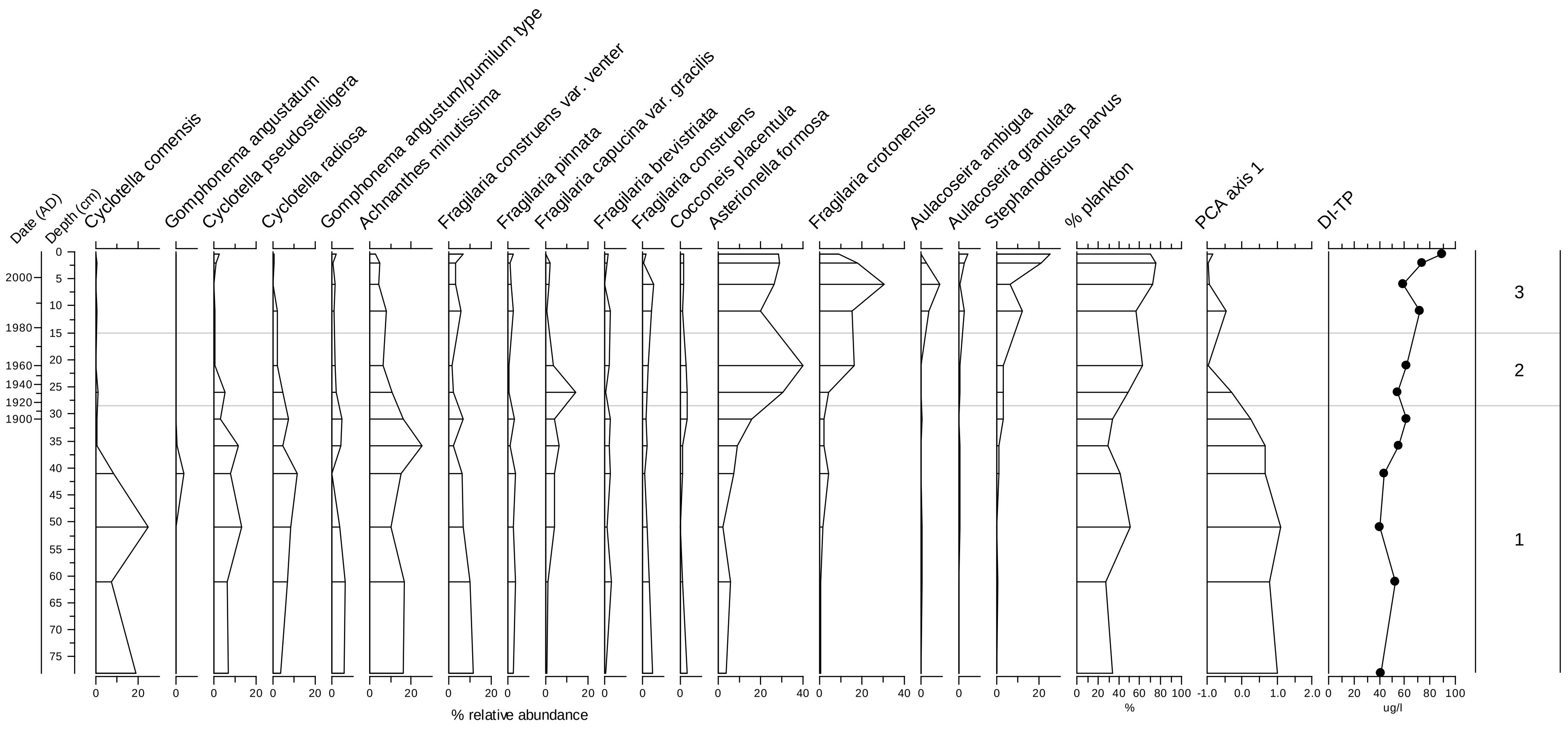
The DI-TP reconstruction suggests that TP concentrations were relatively stable prior to 40 cm at ~40 µg l^{-1}. Values began to increase gradually from this time to a present day DI-TP of ~100 µg l^{-1}. As for the other lochs in this study, the Northwest European transfer function appears to over-estimate TP concentrations for Monzievaird. The measured mean TP reported by SEPA, based on monthly samples from October 2005 to June 2006, was only 37 µg l^{-1}. The reasons for this over-estimation are the same as those given above for White Loch and, likewise, whilst the actual concentrations appear to be over-estimated by the model, there is no reason to believe that the inferred trend is unreliable.

In summary, the diatom assemblages exhibited an initial change at around 1900 and since that time have undergone a succession of species shifts indicative of gradual enrichment of the loch, with the prevalence of nutrient-tolerant taxa by ~1980.

Table 28 Results of the diatom analysis on MONZ1

Depth (cm)	No taxa	N2	DI-TP µg l^{-1}	SCD	PCA axis 1 scores
1	34	6.19	101.93	1.20	-0.8465
2	37	6.25	87.04	1.29	-0.9678
6	31	6.12	75.45	1.29	-0.9475
11	49	11.49	81.92	1.02	-0.4705
21	39	6.06	69.70	1.15	-0.9765
26	48	7.87	57.11	0.85	-0.2962
31	55	10.03	60.50	0.67	0.2552
36	62	8.09	54.72	0.66	0.6478
41	56	8.44	40.02	0.55	0.6626
51	49	6.21	28.79	0.33	1.116
61	58	5.91	44.63	0.32	0.8022
78	53	4.53	30.63	0.00	1.0212

Figure 27 Summary diatom diagram of MONZ1



Cladocera analysis

The Cladocera screening exercise on MONZ1 revealed that remains were relatively sparse throughout the core. However, the numbers were sufficient to proceed with analysis and therefore low resolution analysis of six samples was carried out. The results are presented in Figure 28.

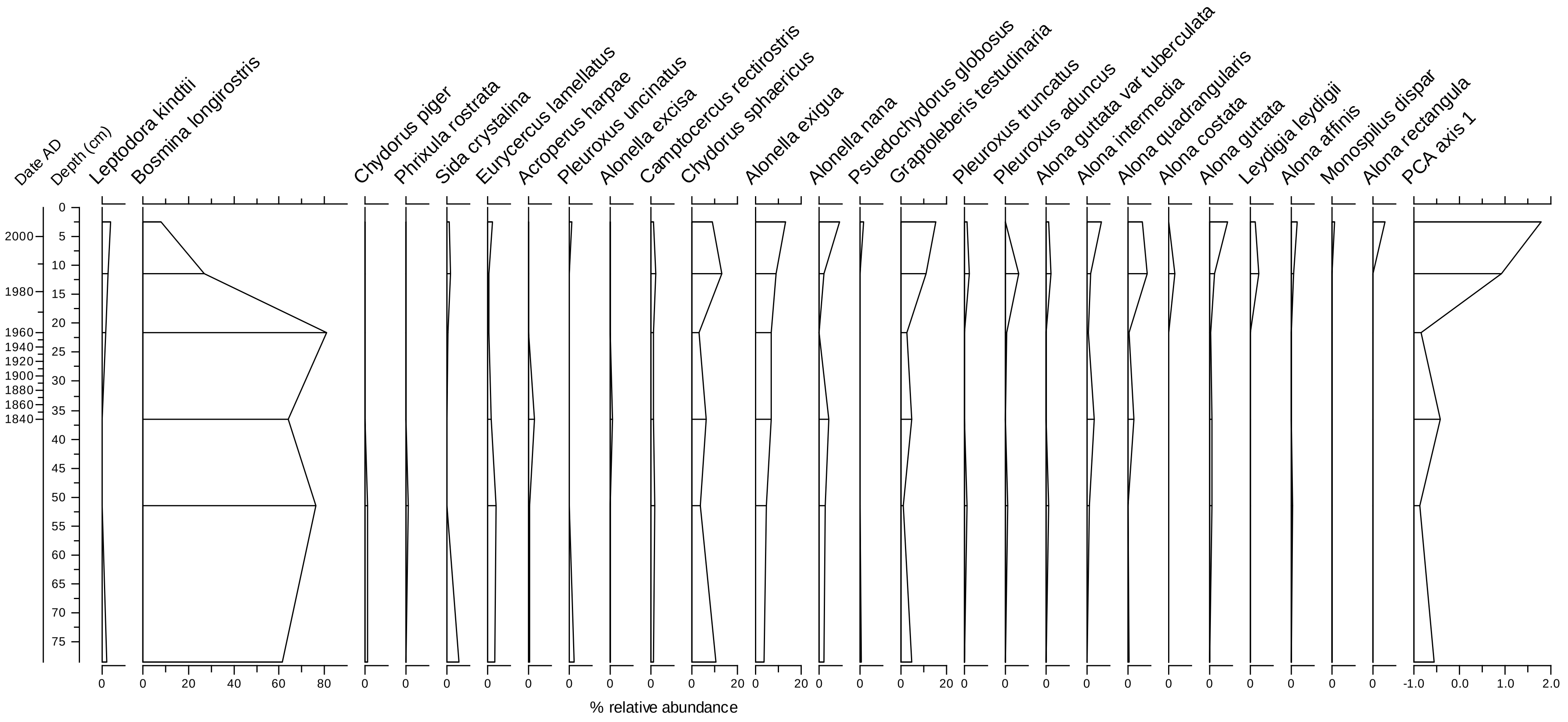
The lower section of the core (pre-1960s) was dominated by high proportions of *Bosmina longirostris* at >60%. Species diversity was very low over this period with N2 values between 1.5 and 2.5 (Table 29). The main shift in the cladoceran record of MONZ1 occurred at 16 cm (the mid-1970s) and is shown by a sharp rise in PCA axis 1 scores. *Bosmina longirostris* fell sharply to a value of <10% by the top-most sample and was replaced by *Chydorus sphaericus, Alonella* species, *Graptoleberis testudinaria* and *Alona* species. Species diversity was greatest in more recent sediments with higher N2 values and nine more taxa present than in the basal sample. This was also reflected by hugely different SCD scores between the core top and base.

In summary, the MONZ1 cladoceran record is characterised by a shift at 16 cm (the mid-1970s) during which the pelagic *Bosmina longirostris* declined and overall species richness of the assemblage increased.

Table 29 Results of the Cladocera analysis on MONZ1

Depth (cm)	No taxa	N2	SCD	PCA axis 1 scores
2.5	23	11.87	0.68	1.7818
11.5	20	7.80	0.41	0.9228
21.5	15	1.51	0.16	-0.8477
36.5	13	2.33	0.18	-0.4299
51.5	16	1.71	0.21	-0.875
78.5	14	2.50	0	-0.552

Figure 28 Summary Cladocera diagram for MONZ1



Macrofossil analysis

The macrofossil screening exercise on the littoral core MONZ2 revealed that macrofossil remains were relatively abundant and full macrofossil analysis of 12 samples was carried out (Table 30).

Plant macrofossils

The cluster analysis identified four major zones in the plant macrofossil record (Figure 29).

Zone 1 (pre ~1850 AD, 75 cm)

Callitriche seeds and *Nymphaea alba* seed fragments dominated the lowermost sample. *Chara* and *Nitella* oospores were also present in relatively low abundances. *Potamogeton* fine leaf fragments and *Potamogeton crispus* remains were also found in the basal sample.

Zone 2 (pre 1850- ~1850 AD, 61-35 cm)

Potamogeton fine leaf and broad leaf species were present throughout most of this zone, with the fine leaf species reaching their highest abundance at 49 cm. *Potamogeton crispus* remains also reached their highest abundance in this zone at 61 cm. *Chara* and *Nitella* oospores increased in the 61 cm sample and remained relatively high throughout Zone 2. *Nymphaea alba* seed fragments and whole seeds were also abundant throughout Zone 2. *Ceratophyllum* spines first occurred at 61 cm and were present throughout the rest of the zone, as were *Callitriche* seeds. Species diversity was generally higher in this zone compared to Zone 1. The PCA axis 1 scores rose slightly at the bottom of Zone 2 reflecting the increase in *Potamogeton* spp diversity.

Zone 3 (~1850-1978 AD, 27-7 cm)

Zone 3 was characterised by decreases in most of the *Potamogeton* species, and *Chara* and *Nitella* oospores also declined after ~1850 AD. *Nymphaea alba* seed fragments, whole seeds and *Nymphaeaceae trychosclereids* were all present in relatively high abundance throughout the zone. *Najas flexilis* first occurred at 27 cm but was absent from the rest of the samples in this zone.

Zone 4 (Post ~1978 AD, 4-2 cm)

Macrofossil remains generally decreased in the upper two samples with decreases evident in *Nymphaea alba* seed fragments and whole seeds, and *Nymphaeaceae trychosclereids* remains, along with *Nitella* and *Chara* oospores. *Najas flexilis* leaf spines first occurred in this zone and were present at relatively high abundances suggesting that the plant persisted for some time after 1978 AD. *Zannichellia palustris* seeds also occurred within this zone. The PCA axis 1 scores remained relatively stable throughout Zones 3 and 4, however, they were generally lower than those in Zones 1 and 2 suggesting that the macrofossil assemblages changed after ~1850 AD.

Zooplankton ephippia

For zooplankton ephippia, the core has been divided into two sections for descriptive purposes and the results are shown in Figure 30.

Pre-~1850 (75-35 cm)

Ephippia remains in the lowermost sample in MONZ2 were relatively sparse with only small numbers of *Camptocercus rectirostris*, *Simocephalus* and *Daphnia hyalina* agg present. *Leydigia* was present at 61 cm but was absent from the rest of the record. *Simocephalus* spp increased to maximum levels at 61 cm. At ~1850 AD (35 cm) *Chydorid* spp occurred along with *Simocephalus* and *Daphnia hyalina* agg.

Post-~1850 (35-0 cm)

In the period after ~1850 AD *Daphnia hyalina* agg. increased in abundance and remained dominant until the upper two samples in which they declined. *Ceriodaphnia* spp first occurred within the record at 23 cm (~1950 AD), increased to maximum abundances at 19 cm but were largely absent from samples between 14 and 2 cm. *Simocephalus* spp numbers were generally low in the period after ~1850 AD.

Table 30 Results of the plant macrofossil analysis on MONZ2

Depth (cm)	No taxa	N2	PCA axis 1 scores
2	6	1.76	-0.6022
4	10	1.31	-0.8101
7	9	4.11	-0.5796
11	12	5.12	-0.4887
14	10	5.19	-0.2502
19	9	3.57	-0.3381
23	7	4.27	-0.558
27	9	4.23	-0.732
35	12	4.80	0.3462
49	14	6.44	0.848
61	15	4.76	2.912
75	10	3.60	0.2527

Figure 29 Summary plant macrofossil diagram for MONZ2

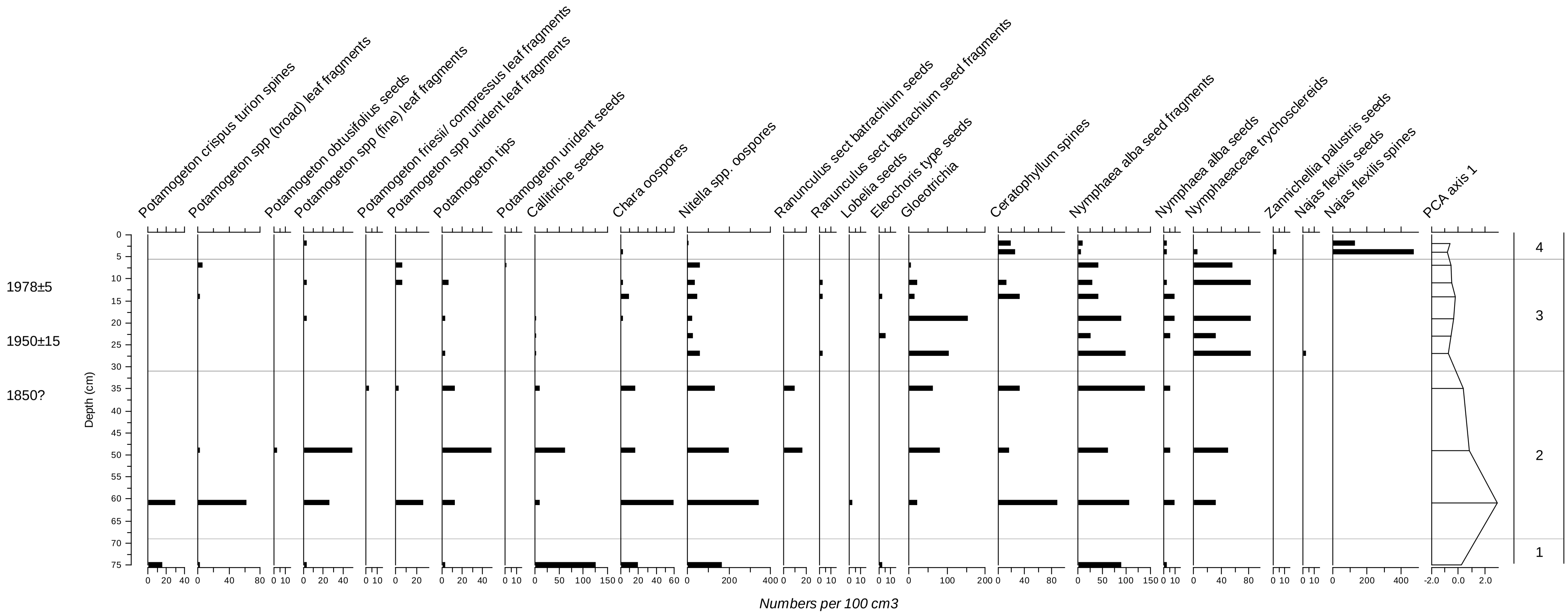
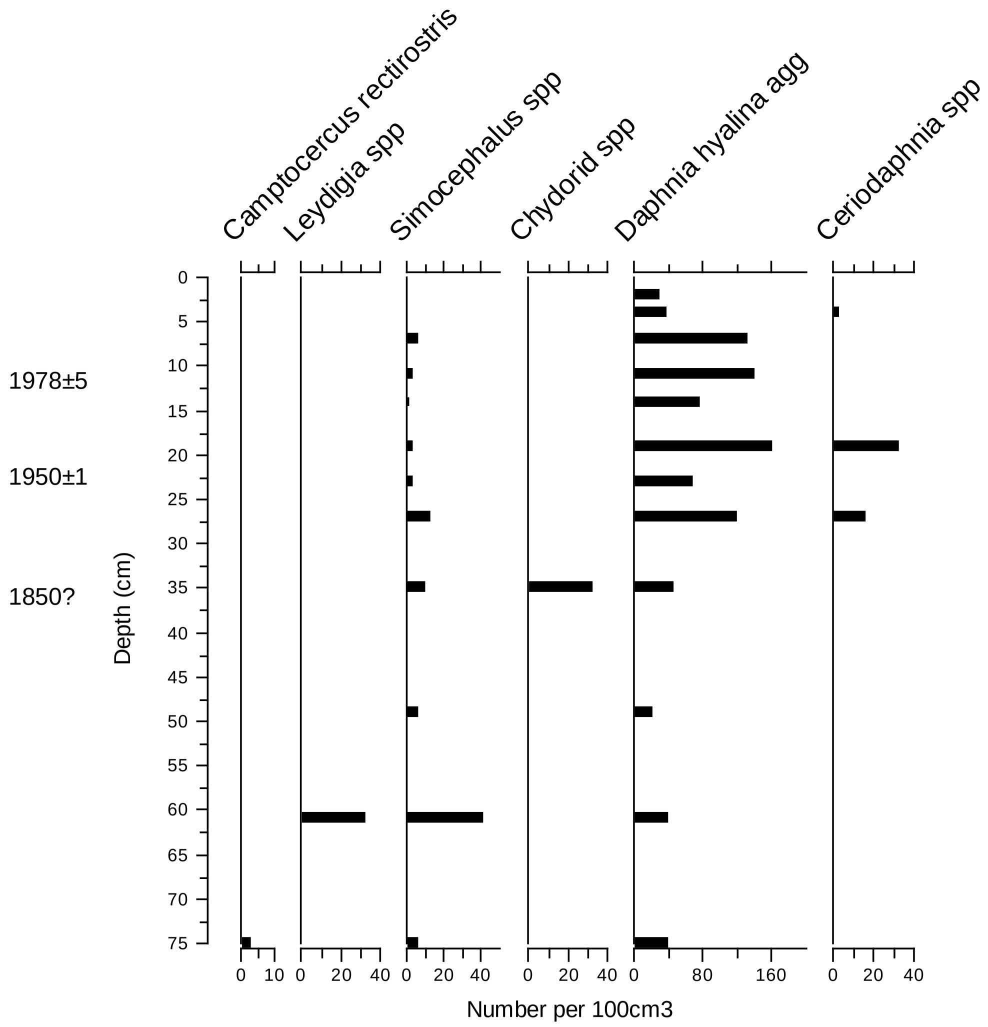


Figure 30 Summary zooplankton ephippia diagram for MONZ2



Discussion

The palaeoecological data indicate that Monzievaird formerly supported a diverse, species-rich submerged and floating-leaved plant community typical of an oligo-mesotrophic loch, comprised of several *Potamogeton* species (including P. *crispus, obtusifolius, friesii/compressus*), *Callitriche*, *Nitella, Chara, Ranunculus, Lobelia, Ceratophyllum* and *Nymphaeaceae.* This was accompanied by a diatom flora associated with relatively unproductive waters, particularly *Cyclotella* taxa (e.g. *Cyclotella comensis, Cyclotella pseudostelligera)* and *Achnanthes minutissima*, and a Cladocera community dominated by *Bosmina longirostris*. However, all of the biological elements experience marked changes over the period represented by the cores, indicative of enrichment.

In the macrofossil record, at around ~1900, the abundance of *Chara, Nitella* and *Callitriche* remains decline, several *Potamogeton* species decline or disappear from the record and *Lobelia* is not present after 1850. Through the early and mid-1900s *Nymphaeaceae* becomes the dominant component of the aquatic vegetation. At the same time in the diatom record (from ~1900) there is a marked decrease in the taxa associated with unproductive waters, whilst several taxa typical of more productive conditions increase in relative abundance, namely the planktonic taxa, *Asterionella formosa* and *Fragilaria crotonesis.* There was no notable change in the Cladocera assemblages at this time as inferred from the chitinous remains although numbers were low in the core and therefore the data must be interpreted with caution. Indeed, analysis of the ephippia indicates that *Daphnia hyalina* agg. and *Ceriodaphnia* spp increased from ~1900 which is in good agreement with the observed expansion of planktonic diatoms at this time which would have provided a food source for the zooplankton.

The second major shift in the records occurs at ~1980. The macrofossil data suggests that whilst *Chara* and *Nitella* are still present, albeit in lower numbers, along with *Ceratophyllum* and *Nymphaeaceae,* overall plant diversity is much reduced. *Zannichellia palustris*, a species associated with elevated nutrient levels (e.g. Davidson *et al*., 2005), arrives and *Najas flexilis* spines are abundant in the upper core. Notably, the remains of *Najas flexilis*, the biodiversity priority species for Monzievaird, were not observed until the 27 cm sample, dated to around the late-1880s, suggesting that this species was probably not part of the reference community, most likely because the loch was too unproductive. *Najas flexilis* was last recorded in the loch by a survey in 1884 but was absent from a shoreline survey conducted in 2000 (Wingfield *et al.,* 2004). However, the high numbers of *Najas flexilis* spines in the uppermost core samples confirm its recent presence and it appears to be able to tolerate the more productive and turbid conditions (Wingfield *et al*., 2005). It is possible that the species was missed in the shoreline survey and hence a snorkel based survey is recommended. Furthermore, the degree of inter-annual variability in macrophyte species composition is relatively unknown, but a number of studies have suggested that for mesotrophic lakes it may be high (e.g. Capers, 2003). Thus, a single year survey may not be sufficient to capture a temporally variable *Najas* population. Surveys could be supplemented by the collection of surface sediment samples (e.g. ten samples in a grid across the site) for macrofossil analysis to identify where in the loch the plant occurs.

The recent changes in the macrofossil record accord well with the diatom data. From ~1980 *Stephanodiscus parvus* expanded along with *Fragilaria crotonensis* and *Aulacoseira* taxa and consequently the percentage of planktonic taxa increased. These shifts indicate further enrichment to more eutrophic conditions and would thereby explain the decline in plant diversity demonstrated by the macrofossil data. The DI-TP reconstruction suggests that TP concentrations were relatively stable prior to ~1900 from which time values began to increase gradually to the present day. As for the other lochs in this study, the Northwest European transfer function appears to over-estimate TP concentrations for Monzievaird but there is no reason to believe that the inferred trend is unreliable. It is difficult to interpret the

Cladocera data with any confidence owing to the low numbers of remains but there do appear to be shifts in the assemblages from ~1980 which are synchronous with the observed changes in the diatom and macrofossil records. Most notably there is a decline in the relative abundance of the pelagic species *Bosmina longirostris* and a concomitant increase in plant associated taxa such as *Chydorus sphaericus, Alonella* species, *Graptoleberis testudinaria* and *Alona* species. There is no such equivocation in the ephippia data which indicate a step change in function at around 30 cm which is coincident with a change in the macrofossil assemblage. The increase in pelagic species reflects a rise in the relative importance of planktonic primary production and perhaps a change in the light climate of the loch. The data suggest an increase in plant biomass in recent decades which has most likely occurred as a result of the higher productivity.

In summary, Monzievaird has experienced marked changes in its plant community with presently few taxa in common with those observed in the reference assemblages. The loch originally supported a species-rich community typical of an oligo-mesotrophic site, then underwent an initial phase of species losses at around 1900 with *Nymphaeaceae* becoming the dominant component of the aquatic vegetation, before undergoing a further phase of enrichment from ~1980 resulting in a loss of plant diversity and marked compositional changes with dominance of taxa associated with relatively productive waters.

CONCLUSIONS AND RECOMMENDATIONS

The study has demonstrated the value of palaeoecological records for defining reference conditions and assessing changes in ecosystem structure and function of a set of mesotrophic lochs. The use of a range of proxies has proved particularly useful whereby diatoms and Cladocera assemblages (including chitinous remains and ephippia) have been employed to identify changes in the algal flora and fauna, respectively, but also to infer changes in productivity and habitat availability, and the macrofossil record has been analysed to determine changes in the aquatic plant communities of the sites. Prior to this study, the plant macrofossil method had been applied, with a few exceptions (e.g. Llangorse Lake, Lake of Menteith in Bennion, 2004), to shallow, high alkalinity systems that had been significantly impacted by eutrophication (e.g. Davidson *et al*., 2005; Zhao *et al*., 2006). Indeed in the original specification of this project the emphasis was on analysis of the well established groups, diatoms and Cladocera, rather than on the macrofossils, principally because the feasibility of the latter in mesotrophic systems was poorly known. However, following the screening exercise on cores from four of the lochs, and the observation that plant remains were abundant, macrofossil analysis was undertaken at four rather than two of the sites. This study has demonstrated that the technique can be successfully employed at a broad range of lake types including sites with relatively deep basins, lower alkalinity, oligotrophic to mesotrophic waters, and lakes where the enrichment effects are rather more subtle than those observed in the shallow lakes of southern England. A summary of the findings for each loch is given below.

At Tangy Loch, the data indicate that it is a naturally nutrient-poor loch, formerly supporting an oligo-mesotrophic flora comprised of *Nitella, Isoetes, Lobelia* and broad-leaved *Potamogeton* spp. The loch remains in good condition with a diverse aquatic macrophyte community. Nevertheless, it has experienced enrichment leading to an increase in planktonic production. The data also suggest that there have been structural changes with compositional shifts in the flora and fauna, and an increase in plant species richness and biomass.

At Loch Nan Gad, the data indicate that it is a naturally nutrient-poor, mildly acidic loch, formerly supporting an oligotrophic flora comprised of *Isoetes, Lobelia, Nitella* and both broad- and fine-leaved *Potamogeton* spp. The loch is currently in good condition and supports a healthy and diverse plant community. Whilst the palaeo-data provide evidence of slight enrichment with an increase in plant abundance and diversity, and increased planktonic production, over the period represented by the cores, none of the plant taxa observed in the lower part of the core have been lost from the record

At Loch Flemington, the data indicate that the site formerly supported a diverse plant community typical of a mesotrophic loch, dominated by *Nitella* with *Myriophyllum alterniflorum, Callitriche, Ranunculus*, *Potamogeton praelongus* and *P. obtusifolius.* The sediment record indicates that the loch has experienced complete turnover in its plant community with presently no taxa in common with those observed in the reference assemblages. The loch underwent an initial phase of species shifts at around 1850 with a period of high diversity, before undergoing a further phase of enrichment resulting in a loss of plant diversity and marked compositional changes.

At Monk Myre, the data indicate that the loch formerly supported diatom and Cladocera communities typical of a mesotrophic loch. These have both undergone changes associated with enrichment over approximately the last 150 years, most notably during ~1950-1970. Whilst the benthic and plant-associated diatom and Cladocera assemblages reflect the continued presence of plants, the degree of change in both biological groups indicates there is likely to have been significant alterations in the submerged macrophyte flora of the site. Macrofossil analysis is, therefore, recommended to assess the changes in the aquatic vegetation.

At White Loch, the data indicate that the site formerly supported a diverse, largely non-planktonic diatom community typical of a mesotrophic loch. However, the diatom flora has undergone changes associated with enrichment, initially in ~1980 with a further phase in the late 1990s, resulting in an increase in the planktonic component. Whilst the Cladocera data indicate that plants have been abundant throughout the period represented by the core and that a diverse plant community is likely to be present today, the shifts may reflect a change in the species composition of the submerged macrophyte flora. Macrofossil analysis is, therefore, strongly recommended to assess changes in the aquatic plant community

At Monzievaird, the data indicate that the site formerly supported a diverse, species-rich plant community typical of an oligo-mesotrophic loch, comprised of several *Potamogeton* species (including P. *crispus, obtusifolius, friesii/compressus*), *Callitriche*, *Nitella, Chara, Ranunculus, Lobelia, Ceratophyllum* and *Nymphaeaceae.* However, all of the biological elements experience marked and synchronous changes over the period represented by the cores, indicative of enrichment. The data suggest that the present day plant community has few taxa in common with those observed in the reference assemblages, having undergone an initial phase of species losses at around 1900 with *Nymphaeaceae* becoming the dominant component of the aquatic vegetation, before undergoing a further phase of enrichment from ~1980 resulting in a loss of plant diversity and marked compositional changes with dominance of taxa associated with relatively productive waters. The cladoceran ephippia data suggest a change in ecological functioning coincident with the step change in the macrofossil flora.

In spite of the great potential of the macrofossil method shown here, this study has also highlighted the need for more methodological work. In particular, the low resolution macrofossil studies at Lochs Tangy and Nan Gad have revealed that six samples is not necessarily sufficient to enable a full and sound interpretation of floristic change. The comparatively detailed studies of Loch Flemington and Monzievaird demonstrate the benefit of analysing a greater number of samples per core in terms of providing a more complete history of changes in the aquatic vegetation. Where resources allow, we therefore propose a minimum of twelve samples in future work of this kind. Given that only six samples were analysed at Lochs Tangy and Nan Gad, the addition of six further samples for macrofossil analysis is recommended. Macrofossil analyses were not carried out at White Loch and Monk Myre yet given the marked changes in the diatom and Cladocera assemblages in cores from these sites, full macrofossil analysis is recommended to assess changes in the aquatic plant community over the last century, and particularly over the last few decades.

The study has produced some interesting findings with respect to the biodiversity priority species, *Najas flexilis*. In Lochs Tangy and Nan Gad, *Najas flexilis* appears only relatively recently in the macrofossil record suggesting that it has not always been present at these sites, most probably because the conditions were too unproductive in the past. In Monzievaird, the current presence of the species was indicated by occurrence of remains in the surface sample even though *Najas flexilis* had not been recorded in recent surveys. It is possible that the species was missed as the survey employed only shoreline methods and hence a snorkel based survey and continued monitoring is recommended. Surveys could be supplemented by the collection of surface sediment samples for macrofossil analysis to identify where in the loch the plant occurs. In Lochs Tangy and Nan Gad the palaeo-data in the uppermost samples confirmed recent presence of the species as recorded in modern surveys. At Loch Flemington the macrofossil record indicated that *Najas flexilis* has been present in the loch for at least the last 100 years and is still present today even though it is not identified as a biodiversity priority species for this loch.

Finally, the study has successfully determined the reference communities and the degree of ecological change in six of the seven lochs over approximately the last 100-150 years. The information will hopefully make a valuable contribution to the development of environmental improvement plans for these sites.

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Appendix 1 Radiometric dating results

1. Tangy Loch

Tangy Loch Pb-210 Data							
Core TANG1							
Code 1	Date 2006						
12 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210 Conc		Cum Unsupp	Std Errors		
		Total	Unsupp	Pb-210	Conc		Cum
cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
1	0.2772	180.63	149.11	528.7	8.97	9.05	32.2
2.5	0.7679	70.21	30.54	895.7	8.27	8.4	54.8
3.5	1.095	60.89	16.44	970.1	9.18	9.35	63.3
4.5	1.4222	62.83	24.17	1035.8	5.31	5.39	69.2
5.5	1.8282	51.37	20.05	1125.3	6.28	6.36	72.8
7.5	2.6402	40.2	-2.85	1195.1	7.44	7.58	87.1
8.5	3.0462	38.83	-4.26	1180.7	8.41	8.56	95.3
9.5	3.4522	47.06	5.57	1183.3	4.98	5.06	100.4
10.5	3.8582	18.4	3.49	1201.4	2.86	2.89	102.2
12.5	4.6139	41	-4.26	1198.5	9.08	9.25	109.1
25.5	9.3784	42.13	1.52	1133.2	4.89	4.98	299.8
39.5	14.6819	43.14	0.97	1198.1	4.86	4.95	394.7
40	14.8713			1200			
12 Ra-226 Data Points							
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
1	0.2772	31.52			1.19		
2.5	0.7679	39.67			1.5		
3.5	1.095	44.45			1.76		
4.5	1.4222	38.66			0.95		
5.5	1.8282	31.32			1.02		
7.5	2.6402	43.05			1.43		
8.5	3.0462	43.09			1.62		
9.5	3.4522	41.49			0.9		
10.5	3.8582	14.91			0.41		
12.5	4.6139	45.26			1.74		
25.5	9.3784	40.61			0.92		
39.5	14.6819	42.17			0.95		

Tangy Loch Cs-137, Cs-134 & Am-241 Data						
Core TANG1						
Code 1 Date 2006.01.24						
12 Data Points						
Depth	Cs-137	Conc	Cs-134	Conc	Am-241	Conc
cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-
1	204.89	2.95	0	0	0	0
2.5	149.25	2.62	0	0	0	0
3.5	85.46	2.27	0	0	0	0
4.5	74.29	1.38	0	0	0	0
5.5	41.9	1.31	1.62	0.7	0	0
7.5	35.34	1.38	0	0	0	0

8.5	22.58	1.4	0	0	0	0
9.5	21.74	0.83	1.04	0.51	0	0
10.5	4.82	0.26	0.85	0.34	0	0
12.5	9.35	1.15	0	0	0	0
25.5	0	0	2.25	0.67	0	0
39.5	0	0	1.5	0.63	0	0

2. Loch Nan Gad

Loch Nan Gad Pb-210 Data							
Core NGAD1							
Code 1	Date 2006	.					
17 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210	Conc	Cum Unsupp	Std Errors		
		Total	Unsupp	Pb-210	Conc		Cum
cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
1	0.1574	287.81	242.72	401.4	13.49	13.64	25.2
5.5	0.9786	180.34	137.4	1921.3	14.12	14.27	120.4
8.5	1.5768	96.76	51.56	2445.2	10.34	10.52	152
10.5	1.9756	154.63	108.59	2750.5	17.04	17.27	162.2
12.5	2.3115	124.41	79.51	3063.9	18.18	18.45	174.2
14.5	2.6474	147.55	98.77	3362.2	16.48	16.7	185.1
17.5	3.1262	101.61	48.68	3701.2	15.12	15.35	199.4
20.5	3.605	107.96	52.96	3944.3	14.25	14.5	212.5
25.5	4.5704	77.59	23.49	4294.3	8.66	8.81	238.9
30.5	5.5754	65.52	16.92	4495.6	7.79	7.93	253.9
35.5	6.5632	48.91	2.06	4565.3	7.15	7.28	265.4
40.5	7.5795	46.34	0.2	4573.4	6.93	7.05	275.3
50.5	9.6756	51.04	6.26	4610.3	6.22	6.33	301.6
70.5	14.3636	32.99	-1.65	4718.3	5.47	5.56	386.9
90.5	18.8977	32.48	-4.56	4577.5	4.64	4.73	458.2
109.5	23.2051	31.48	-2.45	4426.6	6.17	6.27	510.3
137.5	26.6215	48.99	1.2	4405.2	7.14	7.27	562.3
138	26.719			4406.4			
17 Ra-226	Data Points						
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
1	0.1574	45.09			2.02		
5.5	0.9786	42.94			2.06		
8.5	1.5768	45.2			1.92		
10.5	1.9756	46.04			2.8		
12.5	2.3115	44.9			3.13		
14.5	2.6474	48.78			2.73		
17.5	3.1262	52.93			2.65		
20.5	3.605	55			2.7		
25.5	4.5704	54.1			1.62		
30.5	5.5754	48.6			1.48		
35.5	6.5632	46.85			1.36		
40.5	7.5795	46.14			1.32		
50.5	9.6756	44.78			1.2		
70.5	14.3636	34.64			0.98		
90.5	18.8977	37.04			0.91		
109.5	23.2051	33.93			1.11		
137.5	26.6215	47.79			1.36		

Loch Nan Gad Cs-137, Cs-134 & Am-241 Data						
Core NGAD1						
Code 1 Date	2006.01.25					
17 Data Points						
Depth	Cs-137	Conc	Cs-134	Conc	Am-241	Conc
cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-
1	160.29	3.48	0	0	0	0
5.5	205.45	4.59	0	0	0	0
8.5	176.63	3.24	0	0	2.06	0.97
10.5	283.17	6.05	0	0	6.51	1.5
12.5	155.37	4.68	0	0	2.7	1.65
14.5	126.89	4.22	0	0	2.8	1.41
17.5	36.52	2.57	0	0	0	0
20.5	28.37	2.35	0	0	0	0
25.5	14.76	1.2	0	0	0	0
30.5	14.86	1.1	0	0	0	0
35.5	9.56	0.95	0	0	0	0
40.5	5.47	0.75	0	0	0	0
50.5	0	0	0	0	0	0
70.5	0	0	0	0	0	0
90.5	0	0	0	0	0	0
109.5	0	0	0	0	0	0
137.5	0	0	0	0	0	0

Loch Nan Gad (Core NGAD 1) Raw CRS Pb-210 model Chronology								
Code 1	Date 2006							
210-Pb flux = 142.1 +/- 8.6 Bq/m^2/yr								
90% Equilibrium depth = 22.8 cm, or 4.05 g/cm^2								
99% Equilibrium depth = 32.1 cm, or 5.88 g/cm^2								
Depth	Drymass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	4562.9	2006	0				
1	0.1574	4161.5	2003	3	2	0.0534	0.3	8.9
2	0.3399	3761.7	2000	6	2	0.0548	0.304	10
3	0.5224	3400.3	1997	9	2	0.0563	0.307	11.2
4	0.7049	3073.7	1993	13	2	0.0577	0.311	12.4
5	0.8874	2778.4	1990	16	2	0.0591	0.315	13.5
6	1.0783	2546	1987	19	2	0.0712	0.371	15.7
7	1.2777	2365.2	1985	21	2	0.0939	0.479	18.8
8	1.4771	2197.2	1983	23	3	0.1166	0.587	21.9
9	1.6765	2036.9	1980	26	3	0.1089	0.552	22.7
10	1.8759	1884.3	1978	28	3	0.071	0.373	21.3
11	2.0596	1728.4	1975	31	4	0.0537	0.3	22.3
12	2.2275	1571.9	1972	34	4	0.057	0.333	25.9
13	2.3955	1418.1	1968	38	4	0.0535	0.32	27
14	2.5634	1269.2	1965	41	5	0.0431	0.262	25.5

15	2.7272	1136.1	1961	45	5	0.0407	0.251	27.2
16	2.8868	1017.2	1958	48	6	0.0465	0.289	32.1
17	3.0464	910.7	1954	52	7	0.0522	0.327	36.9
18	3.206	815.4	1951	55	7	0.052	0.321	39.5
19	3.3656	730.1	1947	59	8	0.0457	0.273	39.8
20	3.5252	653.7	1944	62	9	0.0395	0.225	40.1
21	3.7015	569.1	1939	67	10	0.0363	0.199	43.1
22	3.8946	481.6	1934	72	12	0.0361	0.195	48.8
23	4.0877	407.6	1928	78	14	0.036	0.191	54.5
24	4.2808	345	1923	83	16	0.0358	0.187	60.2
25	4.4739	292	1918	88	18	0.0357	0.183	65.9
26	4.6709	233.9	1911	95	19	0.0333	0.169	70.9
27	4.8719	177.3	1902	104	21	0.0286	0.145	75.3
28	5.0729	134.4	1893	113	22	0.024	0.121	79.7
29	5.2739	101.9	1884	122	23	0.0193	0.098	84.1
30	5.4749	77.3	1875	131	25	0.0147	0.074	88.5

3. Loch a Phuill

Loch a Phuill Pb-210 Data							
Core PHUI1							
Code 1 Date 2006							
10 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210	Conc	Cum Unsupp	Std Errors		
		Total	Unsupp	Pb-210	Conc		Cum
cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
1	0.0698	247.29	247.29	175.5	20.59	20.59	13.4
5	0.5472	163.7	157.99	1126.9	11.56	11.62	80.1
9.5	1.723	91.92	86.88	2525.1	9.98	10.05	153.4
14.5	3.5501	52.91	45.74	3696.8	6.72	6.77	224.3
19.5	5.6291	50.91	44.98	4639.8	7.38	7.44	268.7
25.5	8.4851	28.56	21.74	5552.7	3.19	3.22	322.9
29.5	10.9123	25.79	17.63	6028.7	4.69	4.74	336.5
34.5	14.6679	7.25	-0.76	6345.5	2.5	2.52	365.9
39.5	19.2459	7.4	-0.74	6311.2	2.26	2.28	381.3
45.5	24.604	11.35	1.56	6333.1	2.24	2.26	399
46	25.0433			6339			
10 Ra-226 Data Points							
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
1	0.0698	0			0		
5	0.5472	5.71			1.14		
9.5	1.723	5.04			1.2		
14.5	3.5501	7.17			0.84		
19.5	5.6291	5.93			0.93		
25.5	8.4851	6.82			0.42		
29.5	10.9123	8.16			0.67		
34.5	14.6679	8.01			0.32		
39.5	19.2459	8.14			0.32		
45.5	24.604	9.79			0.28		

Loch a Phuill Cs-137, Cs-134 & Am-241 Data						
Core PHUI1						
Code 1	Date 2006.01.27					
12 Data Points						
Depth	Cs-137	Conc	Cs-134	Conc	Am-241	Conc
cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-
1	186.08	5.45	3.97	1.97	0	0
5	185.5	3.75	0	0	0	0
9.5	176.66	3.5	0	0	0	0
10.5	165.25	2.2	0	0	1.44	0.52
14.5	136.11	2.46	0	0	1.72	0.54
15.5	116.86	2.89	0	0	1.51	0.74
19.5	96.2	2.35	0	0	1.12	0.68
25.5	43.11	0.82	0	0	0.65	0.28
29.5	29.17	1.02	0	0	0	0
34.5	2.33	0.26	0	0	0	0
39.5	0.5	0.17	0	0	0	0
45.5	0.54	0.16	0	0	0	0

Loch a Phuill Raw CRS Model Pb-210 Chronology								
Core PHUI1								
Code 1 Date 2006								
210-Pb flux = 194.8 +/- 11.6 Bq/m^2/yr								
90% Equilibrium depth = 26.2 cm, or 8.88 g/cm^2								
99% Equilibrium depth = 32.1 cm, or 12.87 g/cm^2								
Depth	Drymass	Cum Unsupp	Chronology			Sedimentation Rate		
		Pb-210	Date	Age	Std			% Std
cm	g/cm^2	Bq/m^2	AD	yr	Error	g/cm^2/yr	cm/yr	Error
0	0	6256.7	2006	0				
1	0.0698	6081.2	2005	1	2	0.0766	0.7	10.7
2	0.1891	5828	2004	2	2	0.0827	0.655	10.7
3	0.3085	5585.3	2002	4	2	0.0888	0.61	10.6
4	0.4279	5352.7	2001	5	2	0.095	0.565	10.6
5	0.5472	5129.8	2000	6	2	0.1011	0.52	10.6
6	0.8085	4779.6	1997	9	2	0.1084	0.498	11.6
7	1.0698	4453.2	1995	11	2	0.1156	0.477	12.6
8	1.3311	4149.2	1993	13	2	0.1229	0.455	13.6
9	1.5924	3865.9	1991	15	2	0.1301	0.434	14.5
10	1.9057	3593.6	1988	18	2	0.1378	0.425	15.5
11	2.2711	3332.7	1986	20	2	0.1459	0.43	16.4
12	2.6366	3090.7	1983	23	3	0.154	0.435	17.3
13	3.002	2866.3	1981	25	3	0.1621	0.439	18.2
14	3.3674	2658.2	1979	27	3	0.1702	0.444	19.1
15	3.758	2445	1976	30	4	0.168	0.426	19.9
16	4.1738	2230.3	1973	33	4	0.1556	0.387	20.8
17	4.5896	2034.5	1970	36	4	0.1431	0.348	21.6
18	5.0054	1855.9	1967	39	5	0.1306	0.308	22.5
19	5.4212	1692.9	1964	42	5	0.1182	0.269	23.3
20	5.8671	1508.7	1960	46	6	0.111	0.245	24.9

21	6.3431	1313.4	1956	50	7	0.1092	0.235	27.3
22	6.8191	1143.5	1951	55	8	0.1073	0.225	29.7
23	7.2951	995.5	1947	59	9	0.1055	0.215	32.1
24	7.7711	866.7	1943	63	10	0.1036	0.206	34.5
25	8.2471	754.5	1938	68	10	0.1018	0.196	37
26	8.7885	611.5	1931	75	13	0.0933	0.174	39.2
27	9.3953	461.3	1922	84	17	0.0781	0.141	41.2
28	10.0021	348	1913	93	22	0.063	0.108	43.3
29	10.6089	262.5	1904	102	26	0.0478	0.075	45.3

4. Loch Flemington

Loch Flemington Pb-210 Data							
Core FLEM1							
Code 1	Date 2006						
11 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210 Conc		Cum Unsupp	Std Errors		
		Total	Unsupp	Pb-210	Conc		Cum
cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
0.5	0.021	188.77	165.12	34.8	16.25	16.54	3
5.5	0.381	190.24	165.5	630	9.43	9.61	46.7
10.5	0.7623	164.61	139.63	1210.3	8.2	8.32	65.2
15.5	1.1944	130.91	99.48	1722	14.47	14.8	82.7
20.5	1.6532	106.95	81.37	2135.5	11.84	12.08	106.6
22.5	1.8623	143.97	110.26	2334.3	22.49	23.01	113.6
25.5	2.2072	89.82	67.53	2635	12.42	12.66	130.7
30.5	2.8865	66.36	42.18	3000.8	8.08	8.24	148.2
35.5	3.6473	52.13	29.51	3270.7	6.56	6.72	159.8
40.5	4.5093	16.12	-5.51	3374.1	7.19	7.38	170
50.5	6.1251	21.6	3.81	3360.4	7.04	7.2	199
51	6.2067			3363			
11 Ra-226 Data Points							
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
0.5	0.021	23.65			3.09		
5.5	0.381	24.74			1.85		
10.5	0.7623	24.98			1.41		
15.5	1.1944	31.43			3.1		
20.5	1.6532	25.58			2.42		
22.5	1.8623	33.71			4.86		
25.5	2.2072	22.29			2.46		
30.5	2.8865	24.18			1.64		
35.5	3.6473	22.62			1.45		
40.5	4.5093	21.63			1.65		
50.5	6.1251	17.79			1.52		

Loch Flemington Cs-137, Cs-134 & Am-241 Data						
Core FLEM1						
Code 1	Date 2006.01.29					
11 Data	Points					
Depth	Cs-137 Conc		Cs-134 Conc		Am-241 Conc	

cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-
0.5	115.54	3.91	0	0	0	0
5.5	114.69	2.28	2.72	1.35	0	0
10.5	126.82	2.04	0	0	0	0
15.5	142.54	3.96	0	0	0	0
20.5	149.99	3.45	0	0	0	0
22.5	150.61	5.31	0	0	0	0
25.5	120.88	3.29	0	0	0	0
30.5	99.42	2.09	0	0	2.46	0.75
35.5	45.21	1.33	0	0	0	0
40.5	17.26	1.14	0	0	0	0
50.5	6.78	0.81	0	0	0	0

Loch Flemington CIC Model Pb-210 Chronology								
Core FLEM1								
Code 1	Date 2006							
90% Equilibrium depth = 36.1 cm, or 3.75 g/cm^2								
99% Equilibrium depth = 36.9 cm, or 3.89 g/cm^2								
Mean accumulation rate = 0.06315 ± 0.00856 g/cm^2/yr								
Depth	Drymass	Unsupp	Chronology			Sedimentation Rate		
		Pb-210 Conc	Date	Age	Std			
cm	g/cm^2	Bq/kg	AD	Yr	Error	g/cm^2/yr	cm/yr	±
0	0	177.4	2006	0				
2	0.129	165.2	2004	2	1	0.0653	0.924	24.3
4	0.273	165.4	2002	4	1	0.0653	0.899	24.3
6	0.4191	162.7	2000	6	1	0.0653	0.873	24.3
8	0.5717	152	1997	9	2	0.0653	0.842	24.3
10	0.7242	142	1995	11	3	0.0653	0.811	24.3
12	0.8919	126.1	1993	13	4	0.0705	0.84	31.4
14	1.0648	110.1	1990	16	5	0.0774	0.89	40.9
16	1.2403	97.5	1988	18	6	0.0822	0.916	48.3
18	1.4238	90	1986	20	6	0.0804	0.873	49.4
20	1.6073	83	1983	23	6	0.0786	0.83	50.5
22	1.81	102.2	1980	26	7	0.0644	0.61	43.4
24	2.0348	86.3	1976	30	7	0.0553	0.468	33.6
26	2.2751	64.4	1972	34	7	0.0508	0.392	26.3
28	2.5468	53.4	1967	39	7	0.0508	0.375	26.3
30	2.8186	44.2	1961	45	7	0.0508	0.357	26.3
32	3.1147	37.9	1955	51	7	0.0508	0.341	26.3
34	3.4191	32.8	1949	57	8	0.0508	0.325	26.3

5. Monk Myre

Monk Myre Pb-210 Data							
Core Monk1							
Code 1	Date 2006						
14 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210	Conc	Cum Unsupp	Std Errors		
		Total	Unsupp Pb-210		Conc		Cum

cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
0.5	0.0275	183.14	101.99	28.1	13.07	13.41	3
10.5	0.6633	198.3	121.38	736.4	10.19	10.43	65.9
20.5	1.3633	179.83	122.26	1589.1	15.84	16.18	114.5
30.5	2.3141	134.92	80.86	2541.2	8.96	9.17	178.8
39.5	3.1283	98.19	47.21	3050.4	8.5	8.72	196.4
50.5	4.1884	99.07	45.05	3539.3	9.84	10.08	217.8
60.5	5.1104	105.37	52.49	3988.1	10.62	10.87	239.9
70.5	6.0494	85.28	35.89	4398.1	11.4	11.69	262.2
80.5	7.1164	104.41	50.78	4855.9	11.44	11.71	289.7
90.5	8.1834	63.65	13.94	5160	10.54	10.96	315.2
99.5	9.1279	85.16	36.78	5382.3	15.24	15.65	337.2
110.5	10.2999	63.13	10.27	5625.9	11.27	11.58	374.8
130.5	12.5934	55.28	-3.37	5705	10.31	10.61	436.9
149.5	15.8228	47.89	-6.2	5550.5	7.16	7.37	525.5
150	15.9221			5544			
14 Ra-226 Data Points (Equilibrium at 115.0cm)							
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
0.5	0.0275	81.15			2.99		
10.5	0.6633	76.92			2.21		
20.5	1.3633	57.57			3.3		
30.5	2.3141	54.06			1.95		
39.5	3.1283	50.98			1.93		
50.5	4.1884	54.02			2.18		
60.5	5.1104	52.88			2.33		
70.5	6.0494	49.39			2.6		
80.5	7.1164	53.63			2.51		
90.5	8.1834	49.71			3		
99.5	9.1279	48.38			3.56		
110.5	10.2999	52.86			2.65		
130.5	12.5934	58.65			2.5		
149.5	15.8228	54.09			1.75		

Monk Myre Cs-137, Cs-134 & Am-241 Data						
Core MONK1						
Code 1 Date	2006.01.30					
14 Data Points						
Depth	Cs-137	Conc	Cs-134	Conc	Am-241	Conc
cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-
0.5	38.12	1.95	0	0	0	0
10.5	55.38	1.73	0	0	0	0
20.5	80.2	3.23	0	0	0	0
30.5	68.35	1.76	3.34	1.42	1.61	0.74
39.5	57.34	1.67	0	0	0	0
50.5	78.24	2.05	0	0	1.4	0.9
60.5	104.86	2.44	0	0	3.13	1.02
70.5	50.83	1.95	0	0	2.9	1.1
80.5	43.02	1.91	0	0	2.27	1.04
90.5	5.04	1.24	0	0	0	0

99.5	0	0	0	0	0	0
110.5	2.11	1.05	0	0	0	0
130.5	0	0	0	0	0	0
149.5	0	0	0	0	0	0

6. White Loch

White Loch Pb-210 Data							
Core WHIE1							
Code 1	Date 2006.						
12 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210 Conc		Cum Unsupp	Std Errors		
		Total	Unsupp	Pb-210	Conc		Cum
cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
0.5	0.0268	544.82	502.23	135.2	29.1	29.56	8.8
4.5	0.272	441.91	408.21	1247.3	26.32	26.79	76.6
10.5	0.7559	444.73	380.88	3155.7	18.05	18.4	159.4
15.5	1.2142	404.69	357.99	4848.2	24.28	24.71	203.3
20.5	1.666	362.18	321.55	6381.9	23.23	23.66	243.9
30.5	2.6216	337.24	296.86	9335.1	27.02	27.51	351.4
39.5	3.7071	241.43	194.04	11960	21.89	22.35	466.3
50.5	5.2232	188.61	150.94	14561.5	19.56	19.98	572.1
60.5	6.6817	169.98	133.11	16630.2	18.36	18.77	649.7
70.5	8.1751	100.97	61	18010.3	12.96	13.3	703.8
80.5	9.7711	71.51	35.46	18761.7	10.6	10.89	732.6
87.5	10.9981	70.49	38.83	19217.1	11.45	11.7	747.3
88	11.0778			19247.4			
12 Ra-226 Data Points (Equilibrium > 88cm)							
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
0.5	0.0268	42.59			5.19		
4.5	0.272	33.7			4.99		
10.5	0.7559	63.85			3.55		
15.5	1.2142	46.7			4.61		
20.5	1.666	40.63			4.47		
30.5	2.6216	40.38			5.18		
39.5	3.7071	47.39			4.49		
50.5	5.2232	37.67			4.09		
60.5	6.6817	36.87			3.9		
70.5	8.1751	39.97			2.98		
80.5	9.7711	36.05			2.49		
87.5	10.9981	31.66			2.42		

White Loch Cs-137, Cs-134 & Am-241 Data						
Core WHIE1						
Code 1 Date 2006.01.30						
12 Data Points						
Depth	Cs-137 Conc		Cs-134 Conc		Am-241 Conc	
cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-

0.5	14.41	2.69	0	0	0	0
4.5	9.67	2.55	0	0	0	0
10.5	14.74	1.82	0	0	0	0
15.5	18.76	2.57	0	0	3.33	1.81
20.5	30.24	2.76	0	0	0	0
30.5	29.97	3.29	0	0	0	0
39.5	36.07	3.23	0	0	0	0
50.5	42.12	3.09	9.51	4.01	0	0
60.5	29.81	2.48	0	0	0	0
70.5	7.69	1.34	0	0	0	0
80.5	5.07	1.17	0	0	0	0
87.5	0	0	0	0	0	0

White Loch CIC Model Pb-210 Chronology								
Core WHIE1								
Code 1	Date 2006							
90% Equilibrium depth = 78.1 cm, or 9.38 g/cm^2								
99% Equilibrium depth = 125.9 cm, or 17.14 g/cm^2								
Mean accumulation rate = 0.12974 ± 0.01058 g/cm^2/yr								
Depth	Dry mass	Unsupp	Chronology			Sedimentation Rate		
		Pb-210 Conc	Date	Age	Std			
cm	g/cm^2	Bq/kg	AD	Yr	Error	g/cm^2/yr	cm/yr	±
0	0	493.5	2006		0			
3	0.1801	441.2	2005	1	2	0.133	1.965	29.3
6	0.393	401.2	2003	3	3	0.133	1.756	29.3
9	0.6349	387.5	2001	5	3	0.133	1.621	29.3
12	0.8934	373.9	1999	7	3	0.1597	1.818	30.1
15	1.1684	360.2	1997	9	3	0.213	2.349	31.7
18	1.4401	339.3	1996	10	3	0.1827	1.984	27.9
21	1.7138	320.3	1994	12	4	0.1434	1.519	23.5
24	2.0005	312.7	1992	14	4	0.1422	1.45	21.8
27	2.2871	305.3	1990	16	4	0.141	1.38	20
30	2.5738	298	1988	18	4	0.1398	1.311	18.3
33	2.9231	263.8	1985	21	4	0.1461	1.287	18.6
36	3.285	228.9	1983	23	4	0.154	1.272	19.3
39	3.6468	198.7	1980	26	5	0.1618	1.257	20
42	4.0517	183.3	1977	29	5	0.1543	1.168	20.4
45	4.4652	171.1	1974	32	5	0.1436	1.065	20.7
48	4.8786	159.8	1971	35	5	0.1329	0.962	21
51	5.2961	150	1968	38	5	0.1233	0.869	21.2
54	5.7337	144.4	1964	42	5	0.1187	0.827	21.3
57	6.1712	139.1	1960	46	5	0.1142	0.786	21.4
60	6.6088	133.9	1956	50	5	0.1096	0.744	21.6
63	7.0551	109.5	1952	54	6	0.1096	0.734	22.3
66	7.5031	86.7	1948	58	7	0.1105	0.73	23.1
69	7.9511	68.6	1943	63	7	0.1114	0.726	23.9
72	8.4145	56.2	1939	67	8	0.1118	0.716	24.3

75	8.8933	47.8	1935	71	9	0.1118	0.701	24.3
78	9.3721	40.6	1931	75	10	0.1118	0.686	24.3
81	9.8587	35.7	1928	78	11	0.1118	0.671	24.3
84	10.3846	37.1	1923	83	10	0.1118	0.657	24.3
87	10.9105	38.6	1919	87	10	0.1118	0.644	24.3

7. Monzievaird

Monzievaird Pb-210 Data							
Core MONZ1							
Code 1	Date 2006						
12 Pb-210 Data Points				Units=BQ			
Depth	Dry Mass	Pb-210	Conc	Cum Unsupp	Std Errors		
		Total	Unsupp	Pb-210	Conc		Cum
cm	g/cm^2	Bq/Kg	Bq/Kg	Bq/m^2	Tot	Uns	Uns
0.5	0.0257	349.04	304.95	78.9	19.19	19.51	5.3
4.5	0.2633	363.5	322.92	824.6	20.72	21.09	52
9.5	0.6923	216.68	170.62	1848.7	16.77	17.14	105.7
15.5	1.3153	222.48	178.86	2937.2	17	17.98	155.1
19.5	1.8273	167.77	122.98	3701	17.64	18.06	187
22.5	2.2374	155.11	117.35	4193.7	16.4	16.87	203.8
25.5	2.6895	125.72	84.72	4646.4	14.85	15.2	217.6
30.5	3.5392	66.81	23.52	5052.2	10.16	10.45	241.8
35.5	4.804	48.4	9.18	5245	7.29	7.53	266.6
39.5	5.9712	58.34	17.55	5395.7	7.85	8.06	281.9
44.5	7.5846	56.37	17.53	5678.7	7.2	7.41	305.9
50.5	9.5694	32.01	-2.48	5828.1	7.97	8.2	338.3
51	9.709			5824.4			
12 Ra-226 Data Points							
Depth	Dry Mass	Ra-226 Conc					
cm	g/cm^2	Bq/Kg					
0.5	0.0257	44.09			3.54		
4.5	0.2633	40.58			3.93		
9.5	0.6923	46.06			3.55		
15.5	1.3153	43.62			5.87		
19.5	1.8273	44.79			3.87		
22.5	2.2374	37.76			3.96		
25.5	2.6895	41			3.25		
30.5	3.5392	43.29			2.43		
35.5	4.804	39.22			1.88		
39.5	5.9712	40.79			1.84		
44.5	7.5846	38.84			1.74		
50.5	9.5694	34.49			1.93		

Monzievaird Cs-137, Cs-134 & Am-241 Data						
Core MONZ1						
Code 1 Date	2006.02.01					
12 Data Points						
Depth	Cs-137	Conc	Cs-134	Conc	Am-241	Conc

cm	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-
0.5	36.49	2.54	7.51	2.48	0	0
4.5	61.8	3.22	0	0	2.85	1.61
9.5	70.39	3.17	0	0	0	0
15.5	90.13	3.43	0	0	0	0
19.5	147.29	4.56	0	0	4.44	1.68
22.5	55.58	2.99	0	0	0	0
25.5	9.07	1.7	0	0	0	0
30.5	4.58	1.17	0	0	0	0
35.5	0	0	0	0	0	0
39.5	2.42	0.75	0	0	0	0
44.5	0	0	0	0	0	0
50.5	0	0	0	0	0	0

Monzievaird CIC Model Pb-210 Chronology								
Core MONZ1								
Code 1	Date 2006							
90% Equilibrium depth = 29.6 cm, or 3.39 g/cm^2								
99% Equilibrium depth = 34.4 cm, or 4.52 g/cm^2								
Mean accumulation rate = 0.04873 ± 0.00892 g/cm^2/yr								
Depth	Drymass	Unsupp Pb-	Chronology			Sedimentation Rate		
		210 Conc	Date	Age	Std			
cm	g/cm^2	Bq/kg	AD	Yr	Error	g/cm^2/yr	cm/yr	±
0	0	311.4	2006	0				
1	0.0554	307.1	2005	1	1	0.0612	1.019	28.3
2	0.1148	311.6	2004	2	1	0.0612	0.964	28.3
3	0.1742	316.1	2003	3	1	0.0612	0.909	28.3
4	0.2336	320.6	2002	4	1	0.0612	0.854	28.3
5	0.3062	303	2001	5	1	0.0612	0.808	28.3
6	0.392	266.7	1999	7	2	0.0612	0.771	28.3
7	0.4778	234.7	1998	8	3	0.0612	0.734	28.3
8	0.5636	206.6	1996	10	3	0.0612	0.696	28.3
9	0.6494	181.9	1995	11	4	0.0612	0.659	28.3
10	0.7442	171.3	1993	13	4	0.0618	0.637	28.5
11	0.8481	172.6	1991	15	4	0.063	0.631	28.9
12	0.9519	174	1990	16	4	0.0641	0.624	29.2
13	1.0557	175.4	1988	18	4	0.0653	0.617	29.6
14	1.1596	176.8	1986	20	4	0.0665	0.611	29.9
15	1.2634	178.2	1984	22	4	0.0676	0.604	30.3
16	1.3793	170.7	1983	23	5	0.0704	0.607	30.7
17	1.5073	155.4	1981	25	5	0.0748	0.62	31.3
18	1.6353	141.5	1979	27	5	0.0792	0.633	31.8
19	1.7633	128.9	1977	29	6	0.0836	0.645	32.3
20	1.8956	122	1975	31	6	0.0775	0.584	31.5
21	2.0324	120.1	1972	34	6	0.0607	0.45	29.4
22	2.1691	118.3	1969	37	6	0.0439	0.315	27.3
23	2.3128	111.1	1965	41	6	0.0356	0.243	26.2

24	2.4635	99.7	1961	45	6	0.0356	0.233	26.2
25	2.6142	89.4	1956	50	6	0.0356	0.223	26.2
26	2.7745	74.5	1951	55	7	0.0356	0.213	26.2
27	2.9444	57.7	1946	60	9	0.0356	0.203	26.2
28	3.1144	44.6	1941	65	11	0.0356	0.193	26.2
29	3.2843	34.5	1937	69	12	0.0356	0.183	26.2
30	3.4542	26.7	1932	74	14	0.0356	0.173	26.2