Atmospheric acidification history of Loch Laidon: a comparison of pollution records from 1985 and 1995 sediment cores

R.J. Flower, N.L. Rose, S. Harlock & P. Appleby

Report to the Rannoch Trust and Scottish Natural Heritage

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EXECUTIVE SUMMARY

- Radiometric dating of sediment cores taken from Loch Laidon in 1985 and 1995 shows close between-core agreement indicating good replicability of the coring and dating methods.

- Diatom analysis shows that there are some consistent floristic differences between the sedimentary assemblages in each core but that the trends in species changes through time are virtually identical.

- The recent pH history of Loch Laidon, inferred from the diatoms in each core, shows that the loch has been acidified since the mid-19th century and that there has been no discernable recovery in lake water acidity during the 10 year period post-dating the 1985 core.

- Despite differences in techniques for analysing spheroidal carbonaceous particles in sediments, the 1985 and 1995 Loch Laidon cores show reasonably good agreement in pre-1985 SCP contamination trends.

- The post-1985 SCP record is one of generally decreasing SCP concentrations and flux showing that atmospheric deposition of these fossil-fuel combustion derived particles has decreased over this period. The trend is consistent with those in many lake sediment profiles analysed in Scotland (Rose et al., 1995).

- To assess the impact of the likely changes in UK acid emission strategies and of the current land-use change experiments in the Loch Laidon catchment, sediment traps have been installed in the Loch and it is recommended that the sediment record is again re-examined in five to ten years time.
INTRODUCTION

Like many oligotrophic softwater lochs in Scotland, Loch Laidon has been acidified by atmospheric pollution (Flower et al. 1988). The process started in the 19th century when industrial emissions began to contribute acidity (as sulphur and nitrogen oxides), heavy metals, fly ash and other trace contaminants in significant quantities to the atmosphere. Acidification of many sensitive freshwater lochs typically proceeded throughout the 20th century (e.g. Battarbee et al. 1988a). However, as a result of industrial decline and implementation of some source controls, UK total acid emissions declined by about a third between the mid-1970s and the mid-1980s (Irwin et al. 1990). This change has been linked to small decreases in the measured acidities of some Scottish lochs during the late 1970s and 1980s (Harriman et al. 1996). Biological improvements over this period are less clear, although diatom communities in two upland lochs in Galloway (Battarbee et al. 1988b, Allott et al. 1992) do show minor floristic recoveries since ca. 1980.

The time-scale and extent of acidification of Loch Laidon was revealed by microfossil and geochemical analysis of a radiometrically dated sediment core retrieved from the loch in 1985 (Flower et al. 1988). The most recent sediment in this core showed no evidence of any significant recovery trend in loch water acidity. Similarly, sediment contamination by spheroidal carbonaceous particles (SCPs), a fly ash component of high temperature fossil fuel burning, showed an increasing trend to the sediment surface (1985). To test if any biologically significant changes or any decline in atmospheric contamination (as defined by SCP analysis) of the loch had occurred in the 10 years subsequent to the 1985 palaeo-survey, re-sampling was carried out in 1995. This re-survey entailed collecting a sediment core from approximately the same location as the 1985 core and analysing it in similar ways.

Changing pollutant deposition patterns and possible lag-effects in biological responses to the late 1970s acid emission decline, makes examination of the sediment record of the intervening 10 years of particular interest. This report presents results of radiometric dating, diatom analysis and SCP analysis of the 1995 sediment core. Using the time scale provided by sediment dating, diatom analysis is used to reconstruct recent trends in water pH and SCP analysis is used to identify recent trends in direct atmospheric contamination. By comparing the 1995 results with those obtained from the earlier core (Flower et al. 1988), not only is the post 1985 sediment record made available but also replicability of the methods for the pre-1985 sediment sections is tested.

THE SITE

Loch Laidon is located within Rannoch Moor in the southern Scottish Highlands (National Grid NN 387547). It is a relatively large loch, being 473 ha in area and having a maximum depth of 39 m (Murray & Pullar 1910). It occupies a glacially over-deepened valley (Figure 1) and has two small sub-basins greater than 25 m deep in the middle-line of the loch. The bathymetry is contoured according to the original data produced by Murray & Pullar (1910).

At the west end, the north-west shore of the loch extends into two large shallow bays and land in this area is currently being used for experimental grazing and land-management trials (Monteith et al. 1996). On the south-east shore land was designated a National Nature
Reserve (in 1958 and extended in 1960) or a Site of Special Scientific Interest (in 1955). Locations of these designated areas and other details of the loch and its catchment are given in Flower et al. 1987, Flower et al. 1988).

METHODOLOGY

In September 1995 several sediment cores were collected from 33 m depth near the centre of the loch (Figure 1). Cores were collected with a Jenkin corer and were sectioned on site at 0.5 cm intervals. All three cores collected had undisturbed sediment water interfaces and the longest one (28 cm) was designated the master core and coded as LAI4.

Laboratory analysis

Sediment core sub-samples were measured for bulk density, percentage dry weight, and loss on ignition according to routine procedures (Stevenson et al. 1987). Sub-samples were also divided for further analysis, for radionuclides, diatoms and SCPs as follows:

Radiometric dating: Sediment samples were analysed for $^{210}$Pb, $^{226}$Ra, $^{137}$Cs and $^{241}$Am by gamma spectrometry using a well-type coaxial low background intrinsic germanium detector fitted with a NaI(Tl) escape suppression shield (Appleby et al. 1986). The $^{210}$Pb and $^{226}$Ra results are given in Table 1, and shown graphically in Figures 2 and 3. The $^{137}$Cs and $^{241}$Am results are given in Table 2 and Figure 4.

Diatom analysis: Dried sediment samples were digested in hydrogen peroxide and acid washed before mounting on glass coverslips for counting in the light microscope at x1000 optical magnification. Details of the method are described in Stevenson et al. (1987).

The sedimentary diatom data was statistically analysed out to reconstruct past pH changes in Loch Laidon using the weighted averaging method (Birks et al. 1990). Also, past floristic change analysis of these data was undertaken using numerical analysis methods available in the statistical package CANOCO (ter Braak 1987).

SCP:s: These were extracted from pre-weighed dried sediment samples by acid digestion according to Rose (1990). Following transfer to glass slides, particles were enumerated under light microscopy at x400 magnification.
1995 (L.I) and in 1990 (L.111). Note that the locations of the two cores collected in 1985 (L.111) and in 1986 (L.11) are localised in the central subbasin.

Bathymetric map of Loch Laidon (re-drawn from Murray & Pullar 1910).
RESULTS

Radiometric dating

Because of the more or less exponential decline of unsupported $^{210}\text{Pb}$ activity in LAI4, right down to the $^{210}\text{Pb}/^{226}\text{Ra}$ equilibrium depth (Figures 2 & 3), there is little significant difference between $^{210}\text{Pb}$ chronologies calculated using the CRS and CIC $^{210}\text{Pb}$ dating models (Appleby & Oldfield 1978). Both models suggest a fairly uniform sediment accumulation rate (SAR) throughout the past 150 years (Figure 4), with a mean SAR for this period of 0.013±0.001 g cm$^{-2}$ yr$^{-1}$ (1.6 mm yr$^{-1}$). A detailed chronology is given in Table 3.

High $^{137}\text{Cs}$ activity detected in the 2-2.5 cm sample appears to record fallout from the 1986 Chernobyl accident (Figure 5). Although the $^{137}\text{Cs}$ profile does not resolve the 1963 weapons fallout peak, this event does appear to be recorded at a depth of c. 6.25 cm (Figure 5) by a distinct peak in $^{241}\text{Am}$ activity (Appleby et al. 1991). Figure 4 shows that the two artificial radionuclide dates inferred from these measurements are in good agreement with the $^{210}\text{Pb}$ chronology.

Diatom analysis

The percentage frequency profiles of diatom taxa occurring at abundances >2% in core LAI4 are shown in Figure 6. The three most abundant taxa (>15% at one or more levels in the core), are *Tabellaria flocculosa*, *Frustulia rhomboides* v. *saxonica*, and *Brachysira vitrea*. These are mainly benthic taxa that are derived from communities growing in the littoral zone of the loch. Planktonic diatoms are particularly uncommon in the upper part of the core; most forms of *T. flocculosa* are benthic but some, categorised here as *Tabellaria flocculosa* [agg.], are planktonic in habit. *Cyclotella kuetzingiana* (note, this is now split into at least two new taxa, *C. rossi* and *C. krammeri*) is planktonic but decreases in abundance up the core. The decrease starts in about 1860 AD (21-23 cm depth). Shortly after the *Cyclotella* decline, benthic *Achnanthes minutissima* and *B. vitrea* show similar changes, beginning ca.1915 (12-14 cm depth), that continue to the core top (1995).

While the fore-going taxa show declining abundances, other taxa, such as *Tabellaria flocculosa*, *Frustulia rhomboides* v. *saxonica*, *Peronia fibula*, and *Navicula leptostriata* all show small but clear trends towards increasing abundances towards the core top. A complete list of the diatom taxa occurring in this core is given in Appendix 1.

Historical pH values, reconstructed from LAI4 diatom data (Figure 7), indicate a small but very clear decline in lake water pH from the mid-19th century to the present (1995). The reconstruction indicates that the pH of Loch Laidon has fallen by about 0.5 pH units over the past 140 years, from pH 5.75 to 5.25 pH in 1994/95. There is a small fluctuation in this declining trend occurring in the late 1970s and again in the early 1990s. The significance of these minor pH increases is difficult to assess, but it may be concluded that during the 1985-1995 period the loch has not acidified further. The modern reconstructed pH value (5.25) underestimates the measured pH of the loch (pH 5.6, in 1994) but only one pH measurement is available for 1994 and the error of the reconstruction method is 0.31 pH units (see Birks et al. 1990).
The SCPs for the LAI4 core are expressed both in terms of concentration and of flux (accumulation rate). The SCP profiles begin in the early 1900s at around 14 cm depth (Figure 8 and Table 4). SCP contamination increases gradually from this period to the 1950s when concentration rises more sharply. There appears to be two SCP concentration peaks between the mid-1960s and the early 1980s, but examination of the SCP flux suggests that it is the latter peak which represents the period of maximum contamination. This 1980s peak is a little later than is usual for Scottish cores (ca. 1978, see Rose et al. 1995). This peak is followed by a marked decline in contamination towards the core top (1995).

### Table 1
**210Pb data for Loch Laidon 1995 core LAI4.**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Dry Mass (g cm⁻²)</th>
<th>210Pb Concentration (Bq kg⁻¹)</th>
<th>Total Bq kg⁻¹</th>
<th>Unsupp Bq kg⁻¹</th>
<th>226Ra Concentration (Bq kg⁻¹)</th>
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</thead>
<tbody>
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<td>1604.7</td>
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<td>1566.1</td>
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</tr>
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<td>2.25</td>
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<td>1543.6</td>
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<td>1505.5</td>
<td>38.6</td>
</tr>
<tr>
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<td>0.23</td>
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<td>26.3</td>
<td>1249.3</td>
<td>26.4</td>
</tr>
<tr>
<td>6.25</td>
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<td>901.7</td>
<td>27.4</td>
<td>860.2</td>
<td>27.6</td>
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<tr>
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<td>514.1</td>
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</tr>
<tr>
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<td>13.1</td>
</tr>
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<td>11.1</td>
<td>93.6</td>
<td>11.3</td>
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<td>99.3</td>
<td>10.4</td>
<td>55.9</td>
<td>10.6</td>
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<td>1.41</td>
<td>85.8</td>
<td>7.6</td>
<td>43.9</td>
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<td>21.8</td>
<td>6.9</td>
</tr>
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<td>81.7</td>
<td>7.8</td>
<td>29.7</td>
<td>8.0</td>
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<td>24.50</td>
<td>1.97</td>
<td>69.1</td>
<td>6.6</td>
<td>19.3</td>
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</tr>
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<td>26.50</td>
<td>2.15</td>
<td>58.9</td>
<td>6.6</td>
<td>9.5</td>
<td>6.8</td>
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<td>28.50</td>
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### Table 2
**137Cs and 241Am data for Loch Laidon 1995 core LAI4.**

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<tr>
<th>Depth (cm)</th>
<th>137Cs Conc (Bq kg⁻¹)</th>
<th>241Am Conc (Bq kg⁻¹)</th>
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<td>0.25</td>
<td>430.5 ± 10.8</td>
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<tr>
<td>2.25</td>
<td>1156.3 ± 16.0</td>
<td>4.0 ± 2.3</td>
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<tr>
<td>4.25</td>
<td>693.1 ± 9.3</td>
<td>7.4 ± 1.5</td>
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<tr>
<td>6.25</td>
<td>628.4 ± 9.4</td>
<td>19.6 ± 1.7</td>
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<td>8.25</td>
<td>318.7 ± 10.0</td>
<td>14.9 ± 2.5</td>
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<tr>
<td>10.25</td>
<td>93.7 ± 3.3</td>
<td>0.0 ± 0.0</td>
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<td>58.1 ± 2.8</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>14.25</td>
<td>48.5 ± 2.3</td>
<td>0.0 ± 0.0</td>
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<tr>
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<td>35.4 ± 2.2</td>
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</tr>
<tr>
<td>18.50</td>
<td>21.8 ± 1.1</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>20.50</td>
<td>17.1 ± 1.2</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>22.50</td>
<td>13.9 ± 1.4</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>24.50</td>
<td>9.4 ± 1.1</td>
<td>0.0 ± 0.0</td>
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<td>26.50</td>
<td>3.9 ± 1.1</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>28.50</td>
<td>5.9 ± 0.9</td>
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Table 3  $^{210}$Pb chronology for Loch Laidon 1995 core LAI4.

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<tr>
<th>Depth (cm)</th>
<th>Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Sedimentation Rate</th>
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<tr>
<td></td>
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<td>Date (AD)</td>
<td>Age (yr) ±</td>
<td>g cm$^{-2}$ y$^{-1}$</td>
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<tr>
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<td>1995</td>
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<td>168 15</td>
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Figure 2  Total $^{210}$Pb activity versus depth in Loch Laidon core 1995 LAI4.
Unsupported $^{210}\text{Pb}$ activity versus depth in Loch Laidon 1995 core LAI4. Note that the unsupported activity measured in core LAI1, collected in 1985, is shown as dash coded curve.
Figure 4 The depth versus age calibration for Loch Laidon core 1995 LAI4. Note that the sediment accumulation rate is shown as a dash coded curve.
Figure 5  $^{137}$Cs and $^{241}$Am activities versus depth in Loch Laidon core 1995 LAI4.
Figure 6

Percentage diatom frequency summary diagram for Loch Laidon 1993

shown. Dates are calculated from jtro measurements.
core LIA. Note that only taxa with frequencies greater than 2% are

Figure 7  Diatom inferred pH values for Loch Laidon sediment cores. Closed circles indicate reconstructed pH values for the 1995 core LAI4 and the open circles indicate reconstructed values for the 1985 core LAI1. Dates are calculated from $^{210}$Pb measurements.
Table 4  SCP data for Loch Laidon 1995 core LAI4.

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<th>Depth (cm)</th>
<th>Particles (gDM$^{-1}$)</th>
<th>Flux (cm$^2$ yr$^{-1}$)</th>
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SCP concentration and flux profiles for Loch Laidon 1995 core LAI4. Dates are calculated from $^{210}$Pb measurements.
COMPARISON OF SEDIMENTARY RECORDS IN THE 1985 AND 1995 CORES

Sediment dating

Both the 1985 (LAI1) and 1995 (LAI4) cores were radio-assayed using the same techniques (Appleby et al. 1986). The resulting unsupported $^{210}$Pb activity profiles are remarkably similar and are compared in Figure 3. Table 5 compares the radionuclide inventories and fluxes. The mean SAR estimated for the 1985 core (LAI1) is 0.014 +/- 0.001 g cm$^{-2}$ yr$^{-1}$ (0.18 cm yr$^{-1}$). This is very close to the SAR estimated for the 1995 core (0.013 +/- 0.001 g cm$^{-2}$ yr$^{-1}$). These results indicate excellent replicability of the sediment coring and the dating techniques. The replicability and accuracy of the sediment dating is emphasised by considering the following:

Since LAI4 post dates LAI1 by 10 years and the accumulation rates are virtually identical, the 25 cm depth in LAI4 should date at 10 years later than 25 cm depth in LAI1. From Table 3 and Flower et al. 1987, 25 cm in LAI1 is 150 years pre-1985 and in LAI4 25 cm is 149 years pre-1995. Mean accumulation rates are always a little uncertain when applied to individual depth samples. Using these mean dry mass accumulation rates, 25 cm should be 137 +/- 11 years old in LAI1 and 155 +/- 12 years old in LAI4. These agree to within the uncertainties of the method.

Because of atmospheric radiocaesium contamination, the $^{137}$Cs profiles in LAI1 and LAI4 are markedly different. In the 1995 core LAI4, a major $^{137}$Cs peak of almost 1200 Bq kg$^{-1}$ occurs at 2.25 cm depth and this must be related to the Chernobyl accident in April 1986. In all other samples in the LAI4 core, the $^{137}$Cs activities are comparable to those in the 1985 (pre-Chernobyl) LAI1 core.

Table 5  Comparison of $^{210}$Pb and $^{137}$Cs inventories in the Loch Laidon cores LAI1 (1985) and LAI4 (1995).

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<th>Core</th>
<th>Unsupported $^{210}$Pb</th>
<th>Weapons $^{137}$Cs</th>
<th>Sedimentation rate (mean)</th>
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<td>Inventory Bq m$^{-2}$</td>
<td>Flux Bq m$^{-2}$ yr$^{-1}$</td>
<td>Inventory Bq m$^{-2}$</td>
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<tr>
<td>LAI1 (1985)</td>
<td>7860 +/- 315</td>
<td>245 +/- 10</td>
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<td>LAI4 (1995)</td>
<td>7730 +/- 190</td>
<td>241 +/- 6</td>
<td>3970 +/- 485</td>
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Diatoms

For comparison of the diatom assemblages in the 1995 core with those published previously (Flower et al. 1987) for the 1985 core, the diatom summary diagram from the latter is reproduced in Figure 9. This Figure is however modified somewhat compared with the
previous version. Diatom taxonomy has been synonymised with protocols agreed during SWAP (Surface Water Acidification Project, see Stevenson et al. 1991) and it is reproduced using TILIAGRAPH software (Grimm 1991). Although taxonomic inconsistencies were minimised by using the same diatom analyst for both cores (R.J.F.) some minor differences remain. This is because the earlier core was not recounted and there have been several post-1985 refinements in taxonomic detail. These involve finer taxonomic discrimination of some of the less common taxa, particularly in the *Eunotia* and *Achnanthes* genera. However, the abundances of these new taxa are insufficient for inclusion in the summary diagram (Figure 9).

Whilst the most common species occurrences and their abundance trends are very similar between the 1985 and 1995 cores, there are some significant and consistent differences in species abundances. Importantly, planktonic *Cyclotella kuetzingiana* is present at frequencies of between 15 and 20% in the pre-1900 section of the 1985 (LAII) core. In the 1995 (LAI1) core this species complex remains at less than 10% abundance throughout the entire section. Another difference is the presence of *Navicula leptostriata* at frequencies of between 2 and 5% in core LAI4 whereas this species is not represented at all at the 2% level in the earlier core.

These differences in species abundances and frequencies between the two cores can be further demonstrated by numerical analysis of the diatom data. Diatom species diversity analysis, as estimated in CANOCO by Hills N2 statistic, of cores LAI1 and LAI4 shows clearly that diatom assemblage diversity in LAI4 is greater than in LAI1 (Figure 10). With the exception of samples from two periods (1960s and 1930s), N2 (or the effective number of species, Hill 1973) is approximately 10 more in LAI4 than in LAI1. There is however an irregular trend tendency towards lower values in the post 1900s core sections and this is more marked for the later core, LAI4.

There are several reasons for the consistent between-core differences in N2 diversity scores. Firstly, because percentage frequency data is used, the proportionately lower abundance of *C. kuetzingiana* in LAI4 will tend to introduce more rare species into the diversity estimate. Since N2 considers abundances as well as species presences, the statistic will increase when dominance by particular species reduces, as well as when more species are present. Secondly, because of post 1985 taxonomic improvements, several less common taxa were sub-divided in the later core. Thirdly, some less common species appear to be naturally more abundant in core LAI4. For example, higher *N. leptostriata* abundances in LAI4 cannot be explained by lower *C. kuetzingiana* counts in the upper part of the core.

Species diversity differences are also shown by comparison of the time tracks (since ca. 1850) of floristic change in cores LAI1 and LAI4. These time tracks consist of sample scores from Principal Components Analysis (PCA, see ter Brak 1987) of the biostratigraphic diatom data. The ordination of PCA axis 1 and 2 sample scores (Figure 11) reflects the floristic composition of each sample in each core and scores are linked sequentially according to individual sediment chronologies. The Figure shows clearly that, whilst the direction of floristic change is virtually identical in each core, LAI4 scores are displaced consistently by about two units on axis 1. The time tracks indicate that axis 2 scores reflect the assemblage composition change as a result of acidification. Axis 1 is more affected by the consistent differences in species presences and abundances between the two cores. Both time tracks
show small differences in direction indicating temporary cessation or reversals of the lake acidification trend. LAI1 shows a fluctuation around 1900 and LAI4 shows a slightly delayed start of acidification (ca. 1857, rather than ca. 1848 in LAI1). Also, both cores indicate a reduction in acidification in the 1950s-1980s with minor interruptions obfuscating the acidification trend in these periods. The significant decline in axis 2 scores in LAI4 since 1991 shows that small floristic change is proceeding through the 1990s.

In Flower et al. (1988) the pH reconstruction for the LAI1 core was carried out using multiple regression methods. More statistically robust and preferred methods were developed in the late 1980s and weighted averaging (Birks et al. 1990) pH reconstruction has been applied to the old 1985 data and reproduced in Figure 7. A comparison of the diatom inferred pH values for each core shows both sets of results are very similar and all paired values fall well within the error of the reconstruction method (see Birks et al. 1990). The pH curves show considerable overlap with the 1985 values being rather less regular than those for the later core. The significance of those periods, when the pH declining trend is reversed, is difficult to assess. The pH reversals are not synchronous in the two cores and these changes probably represent 'noise' in the diatom count data.

SCPs

SCP analysis of the 1985 core (LAI3, note that this is a replicate core of LAI1 core, Flower et al. 1988) was undertaken using the technique of Renberg & Wik (1984). Core LAI4 (1995) was analysed using the later improved technique described in Rose (1994).

The SCP results from the 1985 sediment core (LAI3) are shown in Table 6 and Figure 12. The concentration profile is typical for cores analysed using the techniques available at this time. The start of the record is difficult to ascertain, increasing contamination begins in the early 20th century but presence of SCPs is recorded in the 1880s/1890s. In the 20th century there is a long, steady, increase in SCP concentration until the late 1950s / early 1960s when concentration increases more rapidly to a peak in ca. 1976. This is followed by a slight decline although the surface concentration increases once again. The bulk sediment accumulation rate in the both cores is fairly uniform and consequently the SCP flux and concentration profiles are similar.

In the 1995 LAI4 core, SCP contamination begins during the 1890s, earlier than in LAI3, although at much the same time as the isolated 1880s/1890s SCP peak in this core. This small peak in LAI3, below a series of levels with zero SCPs, suggests the particle presences could be due to core smearing, where SCPs are pushed down the sides of the core tube from higher concentration levels during coring or extruding. Alternatively, the extraction technique used for earlier core (Renberg & Wik 1985) failed to discriminate low particle concentrations. The later technique used for LAI4 is known to be more sensitive (Rose 1990; 1994) than that employed for LAI3 and this is indicated by the initial stages of the 1995 core contamination profile, where, although the increase is still slow and steady, SCP concentrations are generally higher than in LAI3.

The later rapid increase in SCP concentration in the 1995 core LAI4 occurs in the 1950s, again earlier than for LAI3, but more similar to many other Scottish cores (Rose et al., 1995). Perhaps the main significant difference between the two cores is that SCPs show an
increasing trend towards the top of the 1985 LAI3 core but LAI4 indicates a sharply declining contamination trend during the subsequent 10 years. This difference is particularly interesting and marks the value of the particular inter-comparison.

There are, of course, error bars associated with the points on the SCP concentration and flux figures which have not been included for the sake of clarity. Although it is important not to read too much into relatively small fluctuations, the ten year trend of decreasing SCP deposition to Loch Laidon should be highlighted. Although differences in analytical technique produces an offset on the SCP flux axis with the later core showing higher fluxes, the characteristic SCP profile features in the two cores agree well (Figure 13). This result increases confidence that the LAI4 post 1985 results are representative of the atmospheric deposition record of SCPs at Loch Laidon as recorded by the deep water sediments. Had LAI3 and LAI4 shown totally different trends it would have been difficult to make any comparison between the two cores or to assess the post 1985 changes.
Figure 9  Percentage diatom frequency summary diagram for Loch Laidon 1985 core LAIL. Note that only taxa with frequencies greater than 2% are shown. Dates are calculated from $^{210}$Pb measurements. The diagram is redrawn from Flower et al. (1988).
Figure 10  
Diatom assemblage diversity as estimated by Hill's N2 statistic (see text and Hill 1973) for the Loch Laidon 1995 core LAI4 (closed circles) and for the 1985 core LAI1 (open circles). Dates are calculated from $^{210}$Pb measurements.
Figure 11  Principal components analysis (PCA) ordination of the sedimentary diatom assemblages in the Loch Laidon 1995 core LAI4 (closed circles) and for the 1985 core LAI1 (open circles). Samples in each core are joined up into time-tracks according to the $^{210}$Pb chronologies. The direction of floristic change is indicated by an arrow.
Table 6   SCP data for Loch Laidon 1985 core LAI3.

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Figure 12  SCP concentration and flux profiles for Loch Laidon 1985 core LAI3. Dates are calculated from $^{210}$Pb measurements.
Figure 13  Comparison of SCP flux (accumulation rate) profiles for the Loch Laidon 1995 core LAI4 (squares) and for the 1985 core LAI3 (circles). Dates are calculated from $^{210}$Pb measurements.
DISCUSSION

It has already been established that Loch Laidon has been acidified and that acid deposition is the most likely cause (Flower et al. 1988). Based on palaeo-environmental analysis of a sediment core collected in 1985, acidification began in the mid-19th century and fly ash contamination began in the 1930s. The results of analysing the 1995 core show that pre-1985 sedimentary profiles are replicated accurately by the later core. Furthermore, analysis of the 1995 core has provided sediment records of environmental change over the 10 year period subsequent to the earlier core.

Radiometric dating of both the 1985 and 1995 cores show that the sediment accumulation rate is almost identical in the two cores. Similarly, diatom analysis shows near identical down-core trends in species abundance changes. There are, however, some consistent between-core differences in the abundances of several diatom taxa. Although consistent differences between biostratigraphies often occur in replicate cores (Figures 6 & 9, and see Juggins et al. 1996), the reasons for this are unclear. Differences in taxonomic convention cannot account for the marked discrepancies in Cyclotella abundances in the pre-1900 sections of both the 1985 and 1995 cores. It is also inconceivable, in these percentage frequency data, that all the non-planktonic taxa are more abundant in the later core so depressing Cyclotella counts. Diatom preservation is not a problem in either core. Differential supply of diatoms to the accumulating sediments would seem to be one possible explanation of the local differences between cores.

Despite the floristic differences between cores the pre-1985 reconstructed pH histories are well replicated. Diatom diversity is higher in the later core and this can be partly explained by counting differences. However, the trends in floristic changes are very similar in both cores, despite some consistent differences in diatom composition. There is also some evidence of temporary cessations in the lake acidification trend in both the inferred pH and floristic analysis data for the post 1940s periods in both 1985 and 1995 cores. It is not possible to relate directly these fluctuations to the effects of reduced acid emissions in the late 1970s. However, it is clear that the diatom inferred pH trend in the later core shows no lake pH recovery during the preceding 10 years. PCA ordination of the core samples for this period show that the diatom assemblages do continue to change according to PCA axis 2 throughout the 1990s. Although this axis is regarded as indicating acidification, diatoms also respond to other water quality variables such as total aluminium and dissolved organic carbon. The PCA scores thus provide a more ecological picture of the relationships of the samples to the real multivariate nature of the aquatic environment than to a single parameter such as pH (H.J.B. Birks, pers. comm.).

SCPs, produced by high temperature combustion of fossil fuels, are unambiguous indicators of industrial pollutants deposited from the atmosphere. Comparison of the two SCPs records shows clearly that trends in anthropogenic impact (from atmospheric sources) have changed during the ten years post dating the 1985 core. The marked decline in particle contamination of the Loch since the mid-1980s is probably in part a delayed response to declining emissions in the 1970s and in part to improved efficiency of particle arresting strategies at emission sources (mainly power stations). The lack of any discernable trend in diatom inferred pH values for the Loch during this period indicates that acid emissions have remained stable.
The sediment record indicates that the land-management change experiments begun in the early 1990s have, as would be expected given their localised nature, had no discernable effect so far on the quality of open loch water.

This study has demonstrated that sediment records of recent environmental change can be replicated by a repeat coring strategy. The ten year period between the replicate cores taken from Loch Laidon is sufficient to resolve trends in atmospheric contamination of the site. Although the decline in particulate contamination is a positive sign, the lack of any sustained recovery in lake-water pH shows that so far reductions in acid emissions have not been sufficient to mitigate the biological effects of acidification in the Loch.

In August 1996 sediment traps were deployed to the deepest part of the Loch and will be emptied on an annual basis and the accumulated material analysed for diatoms and SCPs. Together with a repeat coring strategy at 5-10 year intervals this will allow the biological effects resulting from changes in UK acid emissions and, possibly, from current catchment land-management experiments to be ascertained.

Acknowledgements

We are very grateful to the Institute of Freshwater Ecology (Edinburgh Laboratory) for making available the Jenkin corer and other equipment for sampling Loch Laidon. Alex Kirika (IFE) gave invaluable help in collecting the 1995 sediment cores. ECRC staff, Helen Bennion and Ewan Shilland, also helped with the field work. Lord Pearson kindly provided permission for access to Loch Laidon. Alan Watt (SOAFD) supplied the modern pH data for the Loch. This work was funded by the Rannoch Trust and Scottish Natural Heritage.
REFERENCES


## APPENDIX 1 Diatom species list for loch laidon cores LAI1 (1985) and LAI4 (1995)

### Core LAI1 - 1985

<table>
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<th>Species</th>
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Core LA11 - 1985

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CY006A Cyclotella kuetzingiana Thwaites 1848
CY009A Cyclotella ocellata Pant. 1902
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EU002C Eunotia pectinalis ventralis (Ehrenb.) Hust. 1911
EU002E Eunotia pectinalis impressa minor (Ehr.) Hust.
EU003A Eunotia praerupta Ehrenb. 1843
EU004A Eunotia tenella (Grun. in Van Heurck) A. Cleve 1895
EU005A Eunotia alpina (Naeg. ex Kutz.) Hust. in A. Schmidt 1913
EU006A Eunotia lunaris (Ehrenb.) Grun. in Van Heurck 1881
EU007A Eunotia bidentula W. Sm. 1856
EU008A Eunotia monodon Ehrenb. 1843
EU008B Eunotia monodon bidens major Hust. 1930
EU009A Eunotia exigua (Breb. ex Kutz.) Rabenh. 1864
EU010A Eunotia faba (Ehrenb.) Grun. in Van Heurck 1881
EU011A Eunotia rhomboidea Hust. 1950
EU012A Eunotia robusta Ralfs in Pritch. 1861
EU013A Eunotia arcus Ehrenb. 1837
EU014A Eunotia bactriana Ehrenb. 1854
EU015A Eunotia denticulata (Breb. ex Kutz.) Rabenh. 1864
EU015B Eunotia denticulata fennica Hust. 1932
EU016A Eunotia diodon Ehrenb. 1837
EU017A Eunotia flexuosa Kutz. 1849
EU019A Eunotia iatriculaensis Foged 1970
EU020A Eunotia meisteri Hust. 1930
EU021A Eunotia sudetica O. Mull. 1898
EU022A Eunotia bigibba Kutz. 1849
EU024A Eunotia glacialis Meister 1912
EU025A Eunotia fallax A. Cleve 1895
EU026A Eunotia praerupta-nana Berg
EU031A Eunotia septentrionalis Ostr. 1898
EU038A Eunotia polyglyphis Grun. in Van Heurck 1881
EU039A Eunotia triodon Ehrenb. 1837
EU040A Eunotia paludosa Grun. 1862
EU047A Eunotia incisa W. Sm. ex Greg. 1854
EU048A Eunotia naegelii Migula 1907
EU049A Eunotia curvata (Kutz.) Lagerst. 1884
EU049B Eunotia curvata subarcuata (Naegeli ex Kutz.) Woodhead & Tweed 1954
EU051A Eunotia vanheurckii Patr. 1958
Core LAI1 - 1985
EU9999 Eunotia sp.
FR001A Fragilaria pinnata Ehrenb. 1843
FR002A Fragilaria construens construens (Ehrenb.) Grun. 1862
FR005D Fragilaria virescens exigua Grun. in Van Heurck 1881
FR007A Fragilaria vaucheriae (Kutz.) J.B. Petersen 1938
FR010A Fragilaria constricta Ehrenb. 1843
FR013A Fragilaria oldenburgiana Hust.
FR015A Fragilaria lata Renberg
FU002B Frustulia rhomboides saxonica (Rabenh.) De Toni 1891
FU002C Frustulia rhomboides elongatissima Bour. & Mang.
FU002F Frustulia rhomboides viridula (Breb. ex Kutz.) Cleve 1894
GM002A Gomphoneis olivaceoides (Hust.) J.R. Carter in J.R. Carter & Watts 1981
GO003A Gomphonema angustatum (Kutz.) Rabenh. 1864
GO004A Gomphonema gracile Ehrenb. 1838
GO006A Gomphonema acuminatum Ehrenb. 1832
GO006C Gomphonema acuminatum coronatum (Ehrenb.) W. Sm. 1853
GO014A Gomphonema intricatum Kutz. 1844
HN001A Hannaea arcus (Ehrenb.) Patr. in Patr. & Reimer 1966
KR001A Krasskella kriegerana (Krasske) R. Ross & Sims 1978
ME019A Melosira arenitii (Kolbe) Nagumo & Kobayasi 1977
NA002A Navicula jaerenfelti Hust. 1942
NA003A Navicula radiosa Kutz. 1844
NA003B Navicula radiosa tenella (Bre. ex Kutz.) Grun. ex Van Heurck 1885
NA005A Navicula seminulum Grun. 1860
NA006A Navicula mediocris Krasske 1932
NA008A Navicula rhyncocephala Kutz. 1844
NA013A Navicula pseudocutiformis Hust. 1930
NA014A Navicula pupula Kutz. 1844
NA015A Navicula hassiaca Krasske 1925
NA016A Navicula indifferens Hust. 1942
NA032A Navicula cocconeiformis Greg. ex Greville 1855
NA036A Navicula perpusilla (Kutz.) Grun. 1860
NA037A Navicula angusta Grun. 1860
NA039A Navicula festiva Krasske 1925
NA040A Navicula hoefleri Choln. in Choln. & Schindler 1953
NA041A Navicula heimansii Van Dam & Kooy,
NA042A Navicula minima Grun. in Van Heurck 1880
NA043A Navicula subatomoides Hust. ex Patr. 1945
NA044A Navicula krasskei Hust. 1930
NA045A Navicula bryophila bryophila J.B. Petersen 1928
NA046A Navicula contenta Grun. in Van Heurck 1885
NA068A Navicula impexa Hust. 1961
NA086A Navicula tantula Hust. 1943
NA099A Navicula bremensis Hust. 1957
NA140A Navicula madumensis E.G. Jorg. 1948
NA156A Navicula leptostriata Jorgensen 1948
NA158A Navicula cumbriensis Haworth 1987

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Core LA11 - 1985
NA9953 Navicula [cf. utermohlii] L. Laidon (RJF) 1986
NA9955 Navicula [cf. vitiosa] L. Hir (SF) 1986
NA9973 Navicula [cf. digitulus] L. Urr (RJF) 1985
NA9976 Navicula [cf. schadei] Ochiltree (RJF) 1985
NA9999 Navicula sp.
NE001A Neidium iridis (Ehrenb.) Cleve 1894
NE003C Neidium affine amphirhynchos (Ehrenb.) Cleve 1894
NE004A Neidium bisulcatum bisulcatum (Lagerst.) Cleve 1894
NE9999 Neidium sp.
NI002A Nitzschia fonticola Grun. in Van Heurck 1881
NI005A Nitzschia perminuta (Grun. in Van Heurck) M. Perag. 1903
NI020B Nitzschia angustata acuta Grun. in Cleve & Grun. 1880
NI025A Nitzschia recta Hantzsch ex Rabenh. 1861
NI029A Nitzschia terrestris (J.B. Petersen) Hust. 1934
OP001A Opephora martyi Herib. 1902
PE002A Peronia fibula (Breb. ex Kutz.) R. Ross 1956
PI002A Pinnularia acuminata W. Sm. 1853
PI005A Pinnularia major (Kutz.) W. Sm. 1853
PI007A Pinnularia viridis (Nitzsch) Ehrenb. 1843
PI008A Pinnularia divergens W. Sm. 1853
PI011A Pinnularia microstauron (Ehrenb.) Cleve 1891
PI012A Pinnularia borealis Ehrenb. 1843
PI013A Pinnularia sistass J.R. Carter 1966
PI015A Pinnularia abajensis (Pant.) R. Ross in Hartley 1986
PI016A Pinnularia divergentissima (Grun.in Van Heurck) Cleve 1896
PI017A Pinnularia carminata Barber & J.R. Carter 1978
PI018A Pinnularia biceps Greg. 1856
PI019A Pinnularia legumen Ehrenb. 1843
PI020A Pinnularia undulata Greg. 1854
PI021A Pinnularia hilsea Janisch ex Rabenh. 1860
PI023A Pinnularia irrorata (Grun. in Van Heurck) Hust. 1939
PI026A Pinnularia tenuis Gregory
PI028A Pinnularia subsolaris (Grun.) Cleve 1896
PI036A Pinnularia leptosoma (Grun. in Van Heurck) Cleve 1896
PI048A Pinnularia brebissonii (Kutz.) Rabenh. 1864
PI9999 Pinnularia sp.
SA001A Stauroneis anceps Ehrenb. 1843
SA001B Stauroneis anceps gracilis Rabenh. 1864
SA003A Stauroneis smithii Grun. 1860
SA005A Stauroneis legumen (Ehrenb.) Kutz. 1844
SA006A Stauroneis phoenicenteron (Nitzsch) Ehrenb. 1943
SA008A Stauroneis producta Grun. in Van Heurck 1880
SE001A Semiorsbis hemicyclus (Ehrenb.) Patr. in Patr. & Reimer 1966
SP001A Stenopterobia intermedia (F.W. Lewis) A. Mayer 1913
SU006A Surirella delicatissima Lewis 1864
SY010A Synedra minuscula Grun. in Van Heurck 1881
SY018A Synedra minuscula Grun. in Van Heurck 1881
SY9999 Synedra sp.

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Core LAI1 - 1985
TA001A Tabellaria flocculosa (Roth) Kutz. 1844
TA001B Tabellaria flocculosa IIIp flocculosa Koppen
TA002A Tabellaria fenestrata (Lyngb.) Kutz. 1844
TA003A Tabellaria binalis (Ehrenb.) Grun. in Van Heurck 1881
TA003B Tabellaria binalis elliptica Flower (unpub) 1986
TA004A Tabellaria quadriseptata Knudson 1952
TA9999 Tabellaria sp.
TE001A Tetracyclus lacustris Ralfs 1843

Core LAI4 - 1995
AC001A Achnanthes lanceolata (Breb. ex Kutz.) Grun. in Cleve & Grun. 1880
AC002A Achnanthes linearis (W. Sm.) Grun. in Cleve & Grun. 1880
AC003A Achnanthes microcephala (Kutz.) Cleve 1896
AC004A Achnanthes pseudoswazi J.R. Carter 1963
AC013A Achnanthes minutissima Kutz. 1833
AC014B Achnanthes austriaca minor L. Grannoch (RJF) 1986
AC014C Achnanthes austriaca helvetica Hust. 1933
AC019A Achnanthes nodosa A. Cleve-Euler 1900
AC022A Achnanthes marginulata Grun. in Cleve & Grun. 1880
AC024A Achnanthes depressa (Cleve) Hust. 1933
AC025A Achnanthes flexella (Kutz.) Brun 1880
AC026A Achnanthes frigida Hust. in A. Schmidt 1937
AC027A Achnanthes holstii Cleve 1881
AC028A Achnanthes saxonica Krasske in Hust. 1933
AC029A Achnanthes sublaevis Hust. 1936
AC035A Achnanthes pusilla Grun. in Cleve & Grun. 1880
AC042A Achnanthes detha
AC045A Achnanthes bicapitata Hust. 1952
AC046A Achnanthes altaica (Poretzky) A. Cleve-Euler 1953
AC048A Achnanthes scotica Jones & Flower
AC9964 Achnanthes minutissima scotica (Carter) RJF 1988
AC9967 Achnanthes cf. adnata RJF 1988
AC9969 Achnanthes [scotica/marginulata] Groningen (RJF) 1988
AC9974 Achnanthes [sp. 6 (fine)] L. Nan Eun (VJJ)
AC9975 Achnanthes [altaica var. minor] L. Grannoch (RJF) 1988
AC9990 Achnanthes [sp. b] L. Fleet (NJA) 1986
AC9994 Achnanthes [sp. a] L. Augher (NJA) 1984
AC9996 Achnanthes cf. levanderi
AC9999 Achnanthes sp.
AS003A Asterionella ralfsii W. Sm. 1856
AU004A Aulacoseira lirata (Ehrenb.) R. Ross in Hartley 1986
AU004B Aulacoseira lirata lacustris (Grun. in Van Heurck) R. Ross in Hartley 1986
AU004D Aulacoseira lirata alpigena (Grun.) Haworth
AU005D Aulacoseira distans tenella (Nygaard) R. Ross in Hartley 1986
AU005J Aulacoseira distans laevissima (Grun.) Haworth
AU010A Aulacoseira perglabra

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AU010B Aulacoseira perglabra florinae
AU014A Aulacoseira nygaardii Camburn
AU9999 Aulacoseira sp.

BR001A Brachysira vitrea (Grun.) R. Ross in Hartley 1986
BR003A Brachysira serians (Breb. ex Kutz.) Round & Mann 1981
BR005A Brachysira zellensis (Grun.) Round & Mann 1981
BR006A Brachysira brebissonii R. Ross in Hartley 1986
BR9999 Brachysira sp.

CA003A Caloneis silicula (Ehrenb.) Cleve 1894
CA005A Caloneis bacillaris (Greg.) Cleve 1894
CM004A Cymbella microcephala Grun. in Van Heurck 1880
CM009A Cymbella naviculiformis Auersw. ex Heib. 1863
CM010A Cymbella perpusilla A. Cleve 1895
CM014A Cymbella aequalis W. Sm. ex Grev. 1855
CM015A Cymbella cesattii (Rabenh.) Grun. in A. Schmidt 1881
CM017A Cymbella hebridica (Grun. ex Cleve) Cleve 1894
CM020A Cymbella gaeumannii Meister 1934
CM031A Cymbella minuta Hilse ex Rabenh. 1862
CM042A Cymbella tumida (Breb. ex Kutz.) Grun. in Van Heurck 1880
CM043A Cymbella naviculacea Grun. ex Cleve 1881
CM047A Cymbella incerta Grun. in Cleve & Moller 1878
CM048A Cymbella lunata W. Sm. in Grev. 1855
CM052A Cymbella descripta (Hust.) Krammer & Lange-Bertalot 1985
CM9999 Cymbella sp.

CO001A Cocconeis placentula Ehrenb. 1838
CY006A Cyclotella kuetzingiana Thwaites 1848
DT002A Diatoma hyemale (Roth) Heib. 1863
EU002A Eunotia pectinalis (O.F. Mull.) Rabenh. 1864
EU002B Eunotia pectinalis minor (Kutz.) Rabenh. 1864
EU002C Eunotia pectinalis ventralis (Ehrenb.) Hust. 1911
EU002E Eunotia pectinalis impressa minor (Ehr.) Hust.
EU004A Eunotia tenella (Grun. in Van Heurck) A. Cleve 1895
EU007A Eunotia bidentula W. Sm. 1856
EU009A Eunotia exigua (Breb. ex Kutz.) Rabenh. 1864
EU011A Eunotia rhomboidea Hust. 1950
EU013A Eunotia arcus Ehrenb. 1837
EU014A Eunotia bactriana Ehrenb. 1854
EU015A Eunotia denticulata (Breb. ex Kutz.) Rabenh. 1864
EU017A Eunotia flexuosa Kutz. 1849
EU019A Eunotia iatriaensis Foged 1970
EU020A Eunotia meisteri Hust. 1930
EU022A Eunotia bigibba Kutz. 1849
EU025A Eunotia fallax A. Cleve 1895
EU026A Eunotia praerupta-nana Berg
EU027A Eunotia trinacria Krasske 1929
EU029A Eunotia valida Hust. 1930
EU032A Eunotia serra Ehrenb. 1837
EU038A Eunotia polyglyphis Grun. in Van Heurck 1881
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EU040A Eunotia paludosa Grun. 1862
EU043A Eunotia elegans Ostr. 1910
EU045A Eunotia nymanniana Grun. in Van Heurck 1881
EU047A Eunotia incisa W. Sm. ex Greg. 1854
EU048A Eunotia naegelii Migula 1907
EU049A Eunotia curvata (Kutz.) Lagerst. 1884
EU049B Eunotia curvata subarcuata (Naegel ex Kutz.) Woodhead & Tweed 1954
EU049D Eunotia curvata attenuata A. Berg (Cleve Euler)
EU050A Eunotia tibia A. Cleve-Euler 1953
EU051A Eunotia vanheurckii Patr. 1958
EU051B Eunotia vanheurckii intermedia (Krasske) Cleve
EU053B Eunotia tridentula perminuta Grun. in Van Heurck 1881
EU056A Eunotia minutissima A. Cleve-Euler 1934
EU057A Eunotia exgracilis A. Berg ex A. Cleve-Euler 1953
EU0951 Eunotia [cf. steineckii] Hoylandet (RJF) 1988
EU0961 Eunotia [vanheurckii var. 1] Round L. Glenhead (RJF) 1988
EU0964 Eunotia [sp. 12 (minor)] L. Grannoch (RJF) 1988
EU0965 Eunotia [sp. 10 (minima)] L. Grannoch (RJF) 1988
EU0974 Eunotia [cf. meisteri] Round L (FB-SW AP) 1987
EU0999 Eunotia sp.
FR001A Fragilaria pinnata Ehrenb. 1843
FR002A Fragilaria construens (Ehrenb.) Grun. 1862
FR002C Fragilaria construens venter (Ehrenb.) Grun. in Van Heurck 1881
FR005D Fragilaria vaucheriae (Kutz.) J.B. Petersen 1938
FR010A Fragilaria constricta Ehrenb. 1843
FR9999 Fragilaria sp.
FU002B Frustulia rhomboides saxonica (Rabenh.) De Toni 1891
FU002D Frustulia rhomboides amphipleuroides (Grun. in Cleve & Grun.) De Toni 1891
FU002F Frustulia rhomboides viridula (Breb. ex Kutz.) Cleve 1894
GO003A Gomphonema angustatum (Kutz.) Rabenh. 1864
GO004A Gomphonema gracile Ehrenb. 1838
GO006C Gomphonema acuminatum coronatum (Ehrenb.) W. Sm. 1853
GO013A Gomphonema parvulum (Kutz.) Kutz. 1849
GO014A Gomphonema intricatum Kutz. 1844
GO019A Gomphonema augur Ehr.
GO9999 Gomphonema sp.
HN001A Hannaea arcus (Ehrenb.) Patr. in Patr. & Reimer 1966
KR001A Krasskella kriegerana (Krasske) R. Ross & Sims 1978
MR001A Meridion circulare (Grev.) Ag. 1831
NA002A Navicula jaeneufeltii Hust. 1942
NA003B Navicula radiosa tenella (Brebb. ex Kutz.) Grun. ex Van Heurck 1885
NA005A Navicula seminulum Grun. 1860
NA006A Navicula mediocris Krasske 1932
NA006B Navicula mediocris atomus Hust.
NA013A Navicula pseudoscutiformis Hust. 1930
NA014A Navicula pupula Kutz. 1844
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NA015A Navicula hassiaca Krasske 1925
NA016A Navicula indifferens Hust. 1942
NA018A Navicula wittrockii (Lagerst.) A. Cleve-Euler 1934
NA032A Navicula cocconeiformis Greg. ex Greville 1855
NA033A Navicula subtilissima Cleve 1891
NA036A Navicula perpusilla (Kutz.) Grun. 1860
NA037A Navicula angusta Grun. 1860
NA039A Navicula festiva Krasske 1925
NA042A Navicula minima Grun. in Van Heurck 1880
NA044A Navicula krasskei Hust. 1930
NA045A Navicula bryophila J.B. Petersen 1928
NA046A Navicula contenta Grun. in Van Heurck 1885
NA068A Navicula impexa Hust. 1961
NA086A Navicula tantula Hust. 1943
NA115A Navicula difficillima Hust. 1950
NA129A Navicula seminuloides Hust. 1937
NA140A Navicula madumensis E.G. Jorg. 1948
NA149A Navicula digitulus Hust. 1943
NA156A Navicula leptostriata Jorgensen 1948
NA158A Navicula cumbricensis Haworth 1987
NA160A Navicula submolesta Hust. 1949
NA167A Navicula hoeferi Sensu Ross et Sims
NA9955 Navicula [cf. vitiosa] L. Hir (SF) 1986
NA9962 Navicula [sp. 2] L. Hir (SF) 1986
NA9963 Navicula [sp. 1] L. Hir (SF) 1986
NA9968 Navicula [subtilissima var. 1] L. Fleet (NJA) 1986
NA9976 Navicula [cf. schadei] Ochiltree (RJF) 1985
NA9995 Navicula sp. a
NA9999 Navicula sp.
NE003A Neidium affine (Ehrenb.) Pfitz. 1871
NE003C Neidium affine amphirhynchus (Ehrenb.) Cleve 1894
NE003D Neidium affine humerus Reimer in Patr. & Reimer 1966
NE004A Neidium bisulcatum (Lagerst.) Cleve 1894
NE006A Neidium alpinum Hust. 1943
NE020A Neidium hercynicum A. Mayer 1917
NE9999 Neidium sp.
NI002A Nitzschia fonticola Grun. in Van Heurck 1881
NI005A Nitzschia perminuta (Grun. in Van Heurck) M. Perag. 1903
NI017A Nitzschia gracilis Hantzsch 1860
NI020B Nitzschia angustata acuta Grun. in Cleve & Grun. 1880
NI025A Nitzschia recta Hantzsch ex Rabenh. 1861
PE002A Peronia fibula (Breb. ex Kutz.) R. Ross 1956
PI007A Pinnularia viridis (Nitzsch) Ehrenb. 1843
PI008A Pinnularia divergens W. Sm. 1853
PI011A Pinnularia microstauron (Ehrenb.) Cleve 1891
PI012A Pinnularia borealis Ehrenb. 1843
PI014A Pinnularia appendiculata (Ag.) Cleve 1896
PI015A Pinnularia abaujensis (Pant.) R. Ross in Hartley 1986

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PIO 17 A Pinnularia carminata Barber & J.R. Carter 1978
PIO 18 A Pinnularia biceps Greg. 1856
PIO 20 A Pinnularia undulata Greg. 1854
PIO 22 A Pinnularia subcapitata Greg. 1856
PIO 22 B Pinnularia subcapitata hilseana (Janisch ex Rabenh.) O. Mull. 1898
PIO 23 A Pinnularia irrorata (Grun. in Van Heurck) Hust. 1939
PIO 24 A Pinnularia stomatophora (Grun. ex A. Schmidt) Cleve 1891
PIO 26 A Pinnularia tenuis Gregory
PIO 30 A Pinnularia acoricola Hust.
PIO 51 A Pinnularia lata (Breb.) W. Sm. 1853
PI 170 A Pinnularia braunii (Grun.) Cleve
PI 9995 Pinnularia [cf. angulata] L. Valley (RJF) 1984
PI 9999 Pinnularia sp.

SA 001 A Stauroneis anceps Ehrenb. 1843
SA 001 B Stauroneis anceps gracilis Rabenh. 1864
SA 005 A Stauroneis legumen (Ehrenb.) Kutz. 1844
SA 9999 Stauroneis sp.

SE 001 A Semiorbis hemicyclus (Ehrenb.) Patr. in Patr. & Reimer 1966
SP 002 A Stenopterobia sigmatella (Greg.) R. Ross in Hartley 1986
SP 9999 Stenopterobia sp.

SU 004 A Surirella biseriata Breb. & God. 1835
SU 005 A Surirella linearis linearis W. Sm. 1853
SU 006 A Surirella delicatissima Lewis 1864
SU 016 A Surirella minuta Breb. ex Kutz. 1849
SU 9999 Surirella sp.

SY 002 A Synedra rumpens Kutz. 1844
SY 003 A Synedra acus Kutz. 1844
SY 010 A Synedra minuscula Grun. in Van Heurck 1888
SY 9999 Synedra sp.

TA 001 A Tabellaria flocculosa (Roth) Kutz. 1844
TA 001 B Tabellaria flocculosa IIIp flocculosa Koppen
TA 003 B Tabellaria binalis elliptica Flower 1986
TA 004 A Tabellaria quadriseptata Knudson 1952

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