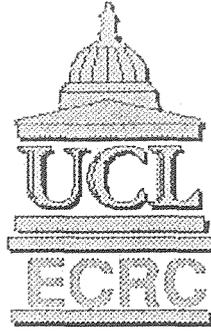


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**ENVIRONMENTAL CHANGE  
RESEARCH CENTRE**

**University College London**

**RESEARCH REPORT**

**No. 29**

**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**

**July 1996**

**Environmental Change Research Centre  
University College London  
26 Bedford Way  
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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  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$ ,  $^{137}\text{Cs}$  and  $^{241}\text{Am}$  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  $^{210}\text{Pb}$  and  $^{226}\text{Ra}$  results are given in Table 1, and shown graphically in Figures 2 and 3. The  $^{137}\text{Cs}$  and  $^{241}\text{Am}$  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).

*SCPs:* 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.

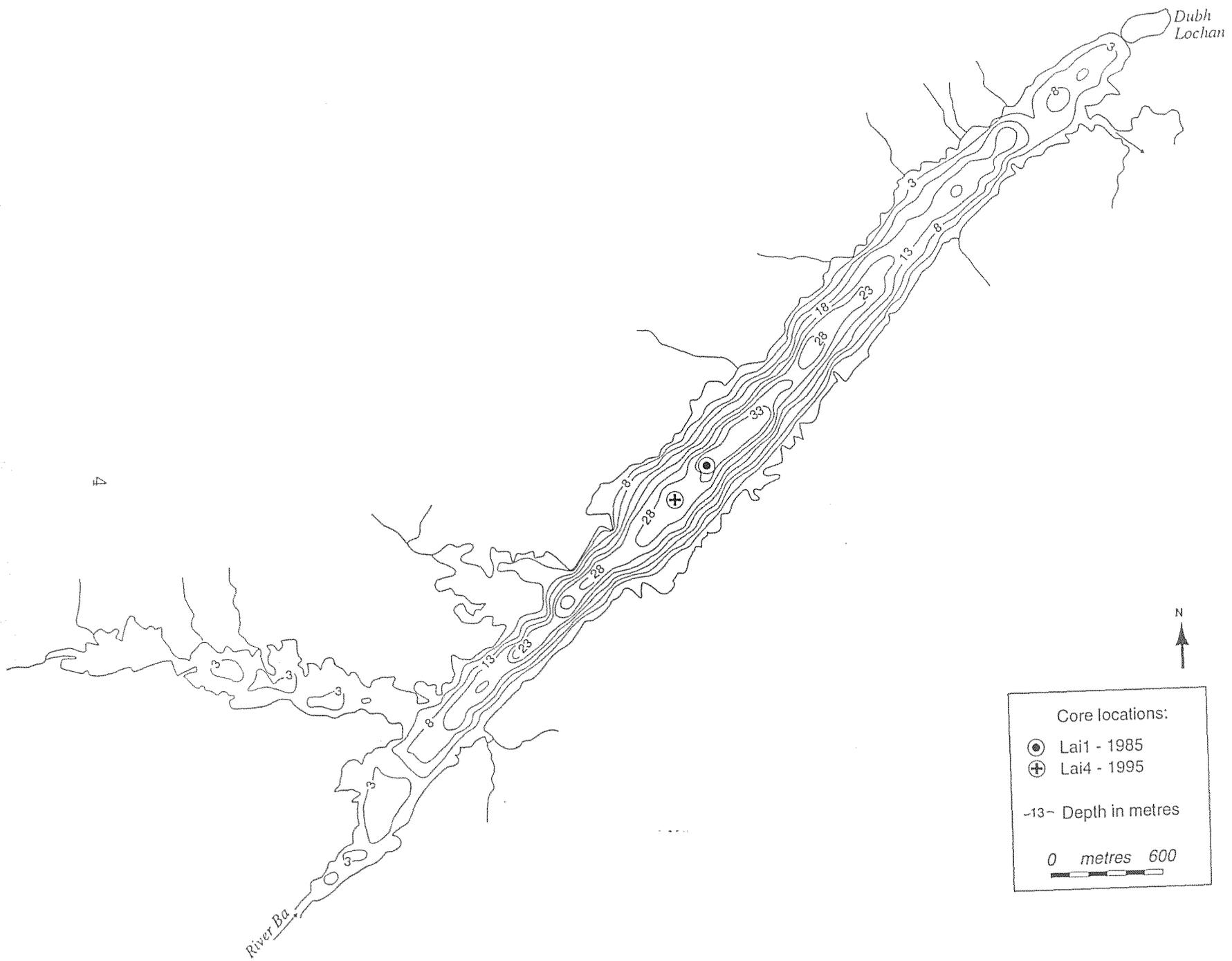


Figure 1 Bathymetric map of Loch Laidon (re-drawn from Murray & Pullar 1910). Note that the locations of the two cores collected in 1985 (LAI1) and in 1995 (LAI4) are located in the central sub-basin.

## 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  $0.013 \pm 0.001 \text{ g cm}^{-2} \text{ yr}^{-1}$  ( $1.6 \text{ mm yr}^{-1}$ ). 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).

## SCPs

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  $^{210}\text{Pb}$  data for Loch Laidon 1995 core LAI4.

Depth cm	Dry Mass $\text{gcm}^{-2}$	$^{210}\text{Pb}$ Concentration				$^{226}\text{Ra}$ Concentration	
		Total $\text{Bq kg}^{-1}$	$\pm$	Unsupp $\text{Bq kg}^{-1}$	$\pm$	$\text{Bq kg}^{-1}$	$\pm$
0.25	0.01	1604.7	45.9	1566.1	46.3	38.6	5.9
2.25	0.09	1543.6	38.3	1505.5	38.6	38.1	4.5
4.25	0.23	1285.4	26.3	1249.3	26.4	36.1	3.0
6.25	0.38	901.7	27.4	860.2	27.6	41.5	3.0
8.25	0.54	556.2	33.9	514.1	34.2	42.1	4.2
10.25	0.71	351.3	16.9	313.8	17.1	37.5	2.7
12.25	0.87	217.4	12.9	170.8	13.1	46.6	2.3
14.25	1.05	136.0	11.1	93.6	11.3	42.4	1.9
16.50	1.24	99.3	10.4	55.9	10.6	43.4	2.2
18.50	1.41	85.8	7.6	43.9	7.8	41.9	1.3
20.50	1.59	60.7	6.8	21.8	6.9	38.9	1.2
22.50	1.77	81.7	7.8	29.7	8.0	51.9	1.7
24.50	1.97	69.1	6.6	19.3	6.8	49.8	1.5
26.50	2.15	58.9	6.6	9.5	6.8	49.4	1.6
28.50	2.34	60.6	6.2	11.4	6.3	49.2	1.3

Table 2  $^{137}\text{Cs}$  and  $^{241}\text{Am}$  data for Loch Laidon 1995 core LAI4.

Depth cm	$^{137}\text{Cs}$ Conc		$^{241}\text{Am}$ Conc	
	$\text{Bq kg}^{-1}$	$\pm$	$\text{Bq kg}^{-1}$	$\pm$
0.25	430.5	10.8	0.0	0.0
2.25	1156.3	16.0	4.0	2.3
4.25	693.1	9.3	7.4	1.5
6.25	628.4	9.4	19.6	1.7
8.25	318.7	10.0	14.9	2.5
10.25	93.7	3.3	0.0	0.0
12.25	58.1	2.8	0.0	0.0
14.25	48.5	2.3	0.0	0.0
16.50	35.4	2.2	0.0	0.0
18.50	21.8	1.1	0.0	0.0
20.50	17.1	1.2	0.0	0.0
22.50	13.9	1.4	0.0	0.0
24.50	9.4	1.1	0.0	0.0
26.50	3.9	1.1	0.0	0.0
28.50	5.9	0.9	0.0	0.0

Table 3  $^{210}\text{Pb}$  chronology for Loch Laidon 1995 core LAI4.

Depth	Dry Mass	Chronology			Sedimentation Rate		
		Date	Age		$\text{gcm}^{-2}\text{y}^{-1}$	$\text{cm y}^{-1}$	$\pm$ (%)
cm	$\text{gcm}^{-2}$	AD	yr	$\pm$			
0.00	0.00	1995	0				
1.00	0.04	1992	3	2	0.014	0.31	3.8
2.00	0.08	1989	6	2	0.013	0.25	3.8
3.00	0.15	1984	11	2	0.012	0.20	3.8
4.00	0.21	1978	17	2	0.011	0.16	3.8
5.00	0.29	1972	23	2	0.011	0.14	4.2
6.00	0.36	1964	31	2	0.010	0.13	4.8
7.00	0.44	1957	38	2	0.010	0.13	6.0
8.00	0.52	1949	46	2	0.011	0.13	7.5
9.00	0.61	1941	54	2	0.011	0.13	7.8
10.00	0.69	1933	62	2	0.011	0.13	7.6
11.00	0.77	1926	69	2	0.011	0.14	8.6
12.00	0.85	1919	76	3	0.012	0.14	10.0
13.00	0.94	1912	83	3	0.013	0.16	12.2
14.00	1.03	1906	89	3	0.015	0.17	14.5
15.00	1.11	1900	95	4	0.016	0.19	17.4
16.00	1.20	1895	100	4	0.017	0.20	20.5
17.00	1.28	1890	105	4	0.017	0.21	22.3
18.00	1.36	1885	110	5	0.017	0.20	22.5
19.00	1.45	1880	115	5	0.019	0.21	26.1
20.00	1.54	1876	119	6	0.023	0.25	32.8
21.00	1.64	1871	124	6	0.022	0.24	35.6
22.00	1.73	1866	129	7	0.017	0.18	34.5
23.00	1.82	1860	135	8	0.014	0.14	36.7
24.00	1.92	1853	142	9	0.013	0.14	42.4
25.00	2.01	1846	149	10	0.015	0.16	53.6
26.00	2.10	1840	155	11	0.017	0.19	70.5
27.00	2.20	1834	161	13	0.017	0.18	77.8
28.00	2.29	1827	168	15	0.012	0.13	75.6

Figure 2 Total  $^{210}\text{Pb}$  activity versus depth in Loch Laidon core 1995 LAI4.

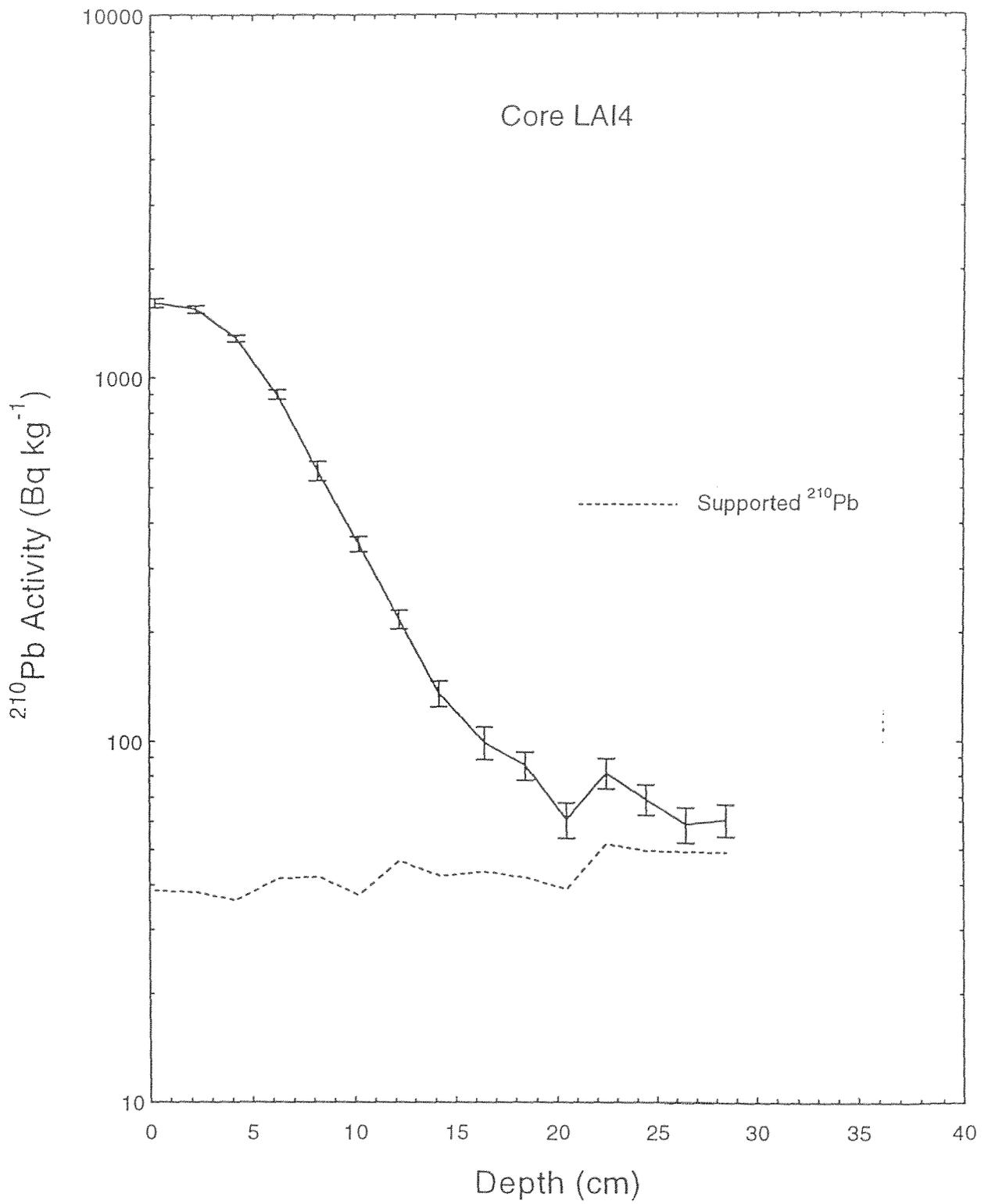


Figure 3 Unsupported  $^{210}\text{Pb}$  activity versus depth in Loch Laidon 1995 core LAI4. Note that the unsupported activity measured in core LAI1, collected in 1985, is shown as dash coded curve.

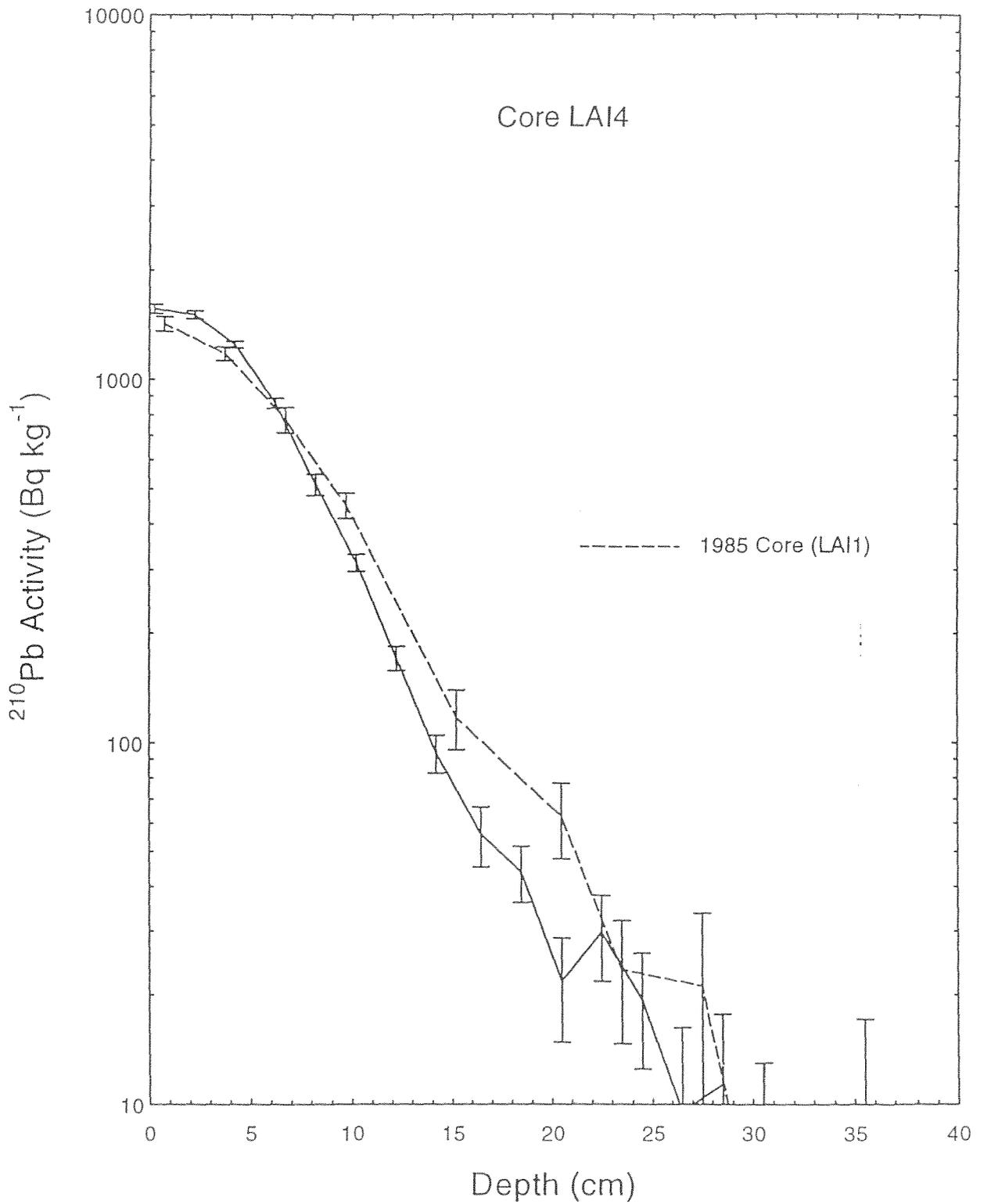


Figure 4 The depth versus age calibration for Loch Laidon core 1995 LAI4. Note that the sediment accumulation rate is shown as a dash coded curve.

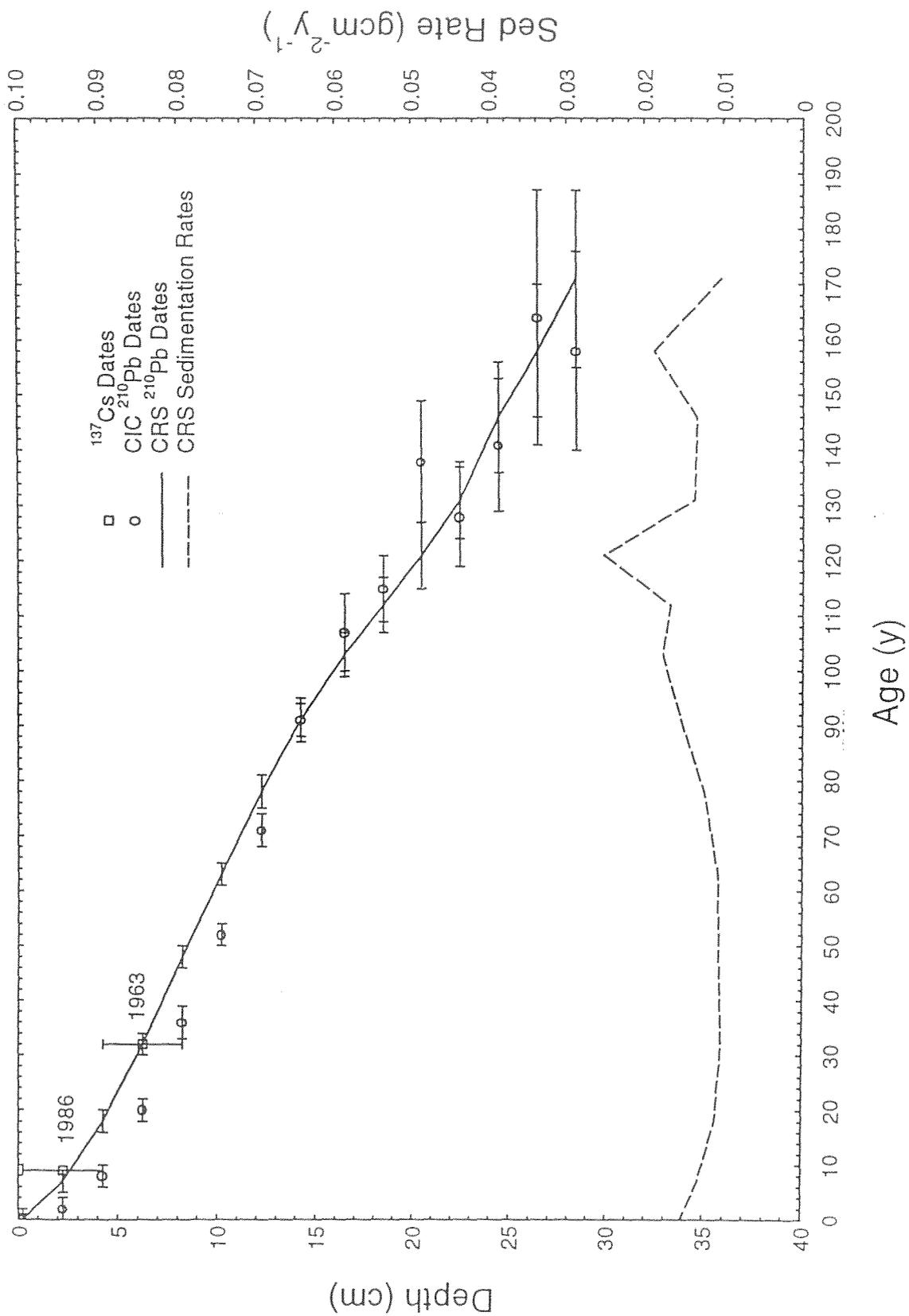


Figure 5  $^{137}\text{Cs}$  and  $^{241}\text{Am}$  activities versus depth in Loch Laidon core 1995 LAI4.

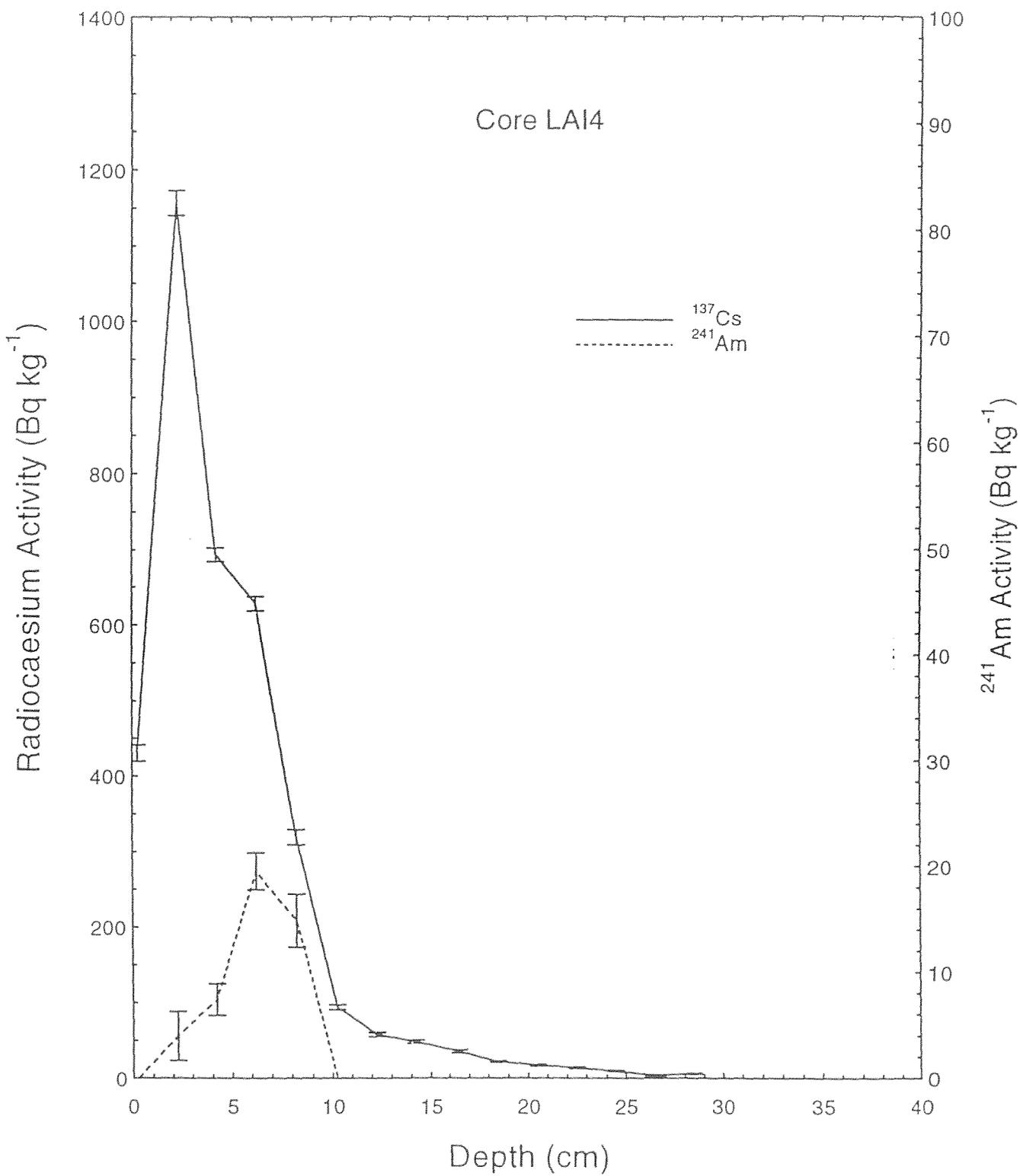


Figure 6 Percentage diatom frequency summary diagram for Loch Laidon 1995 core LA14. Note that only taxa with frequencies greater than 2% are shown. Dates are calculated from  $^{210}\text{Pb}$  measurements.

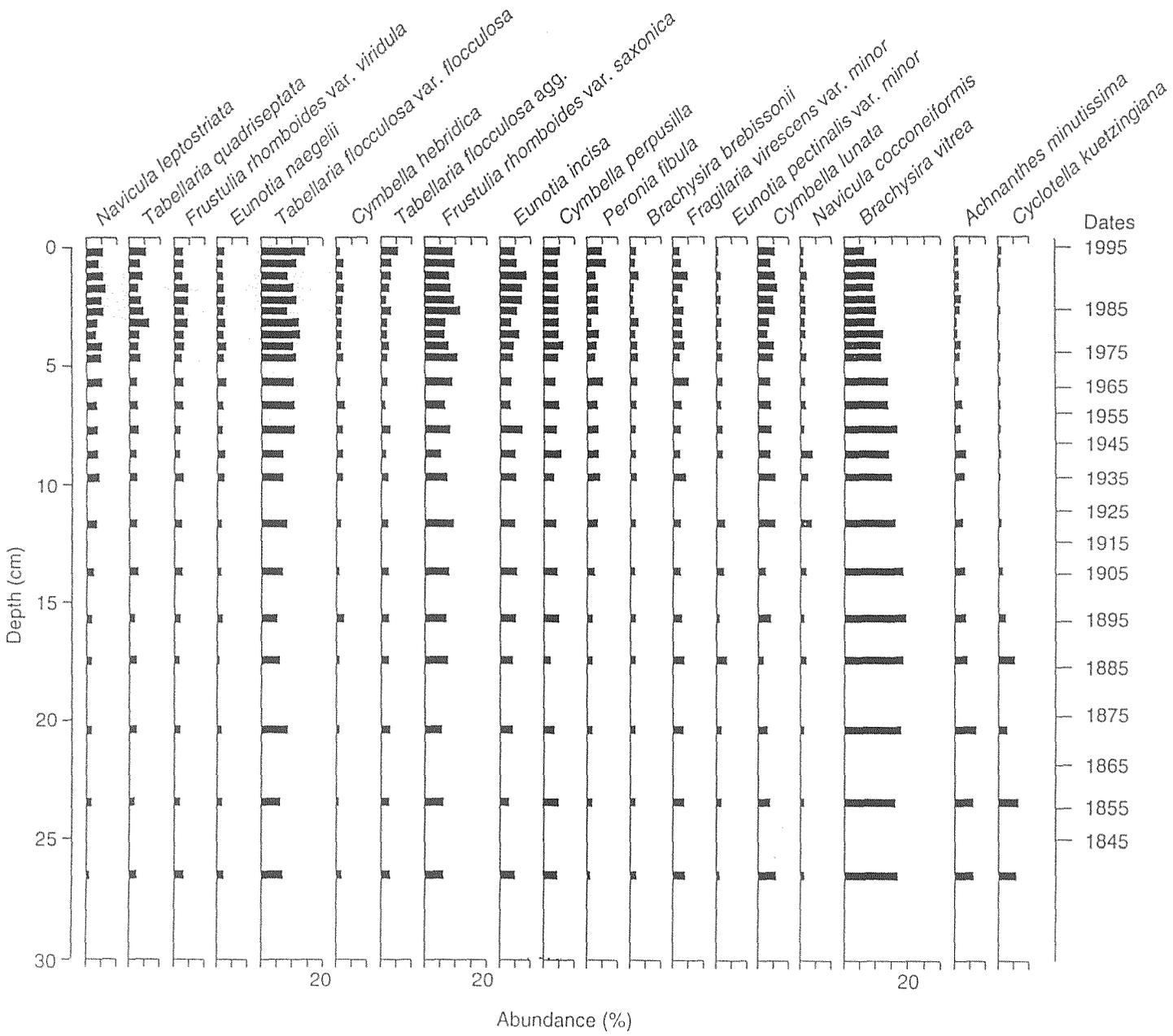


Figure 7 Diatom inferred pH values for Loch Laidon sediment cores. Closed circles indicate reconstructed pH values for the 1995 core LAI4 and the open circles indicate reconstructed values for the 1985 core LAI1. Dates are calculated from  $^{210}\text{Pb}$  measurements.

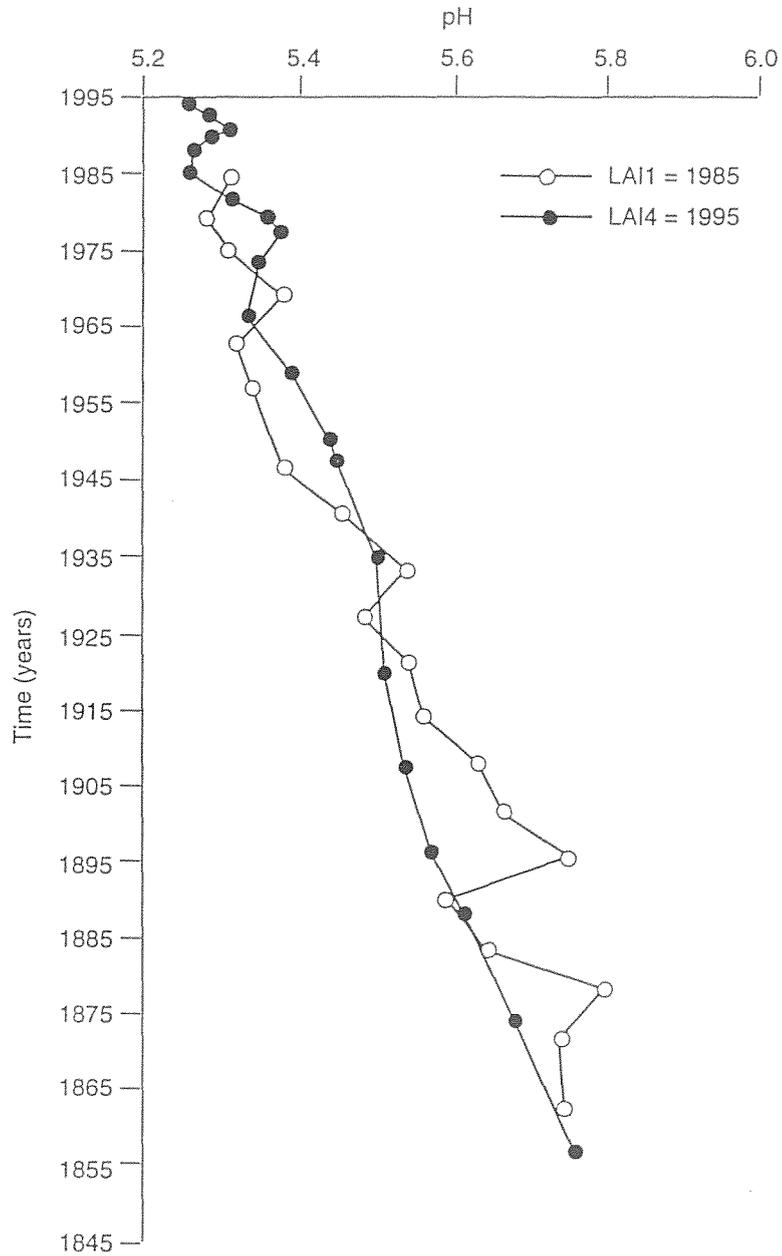
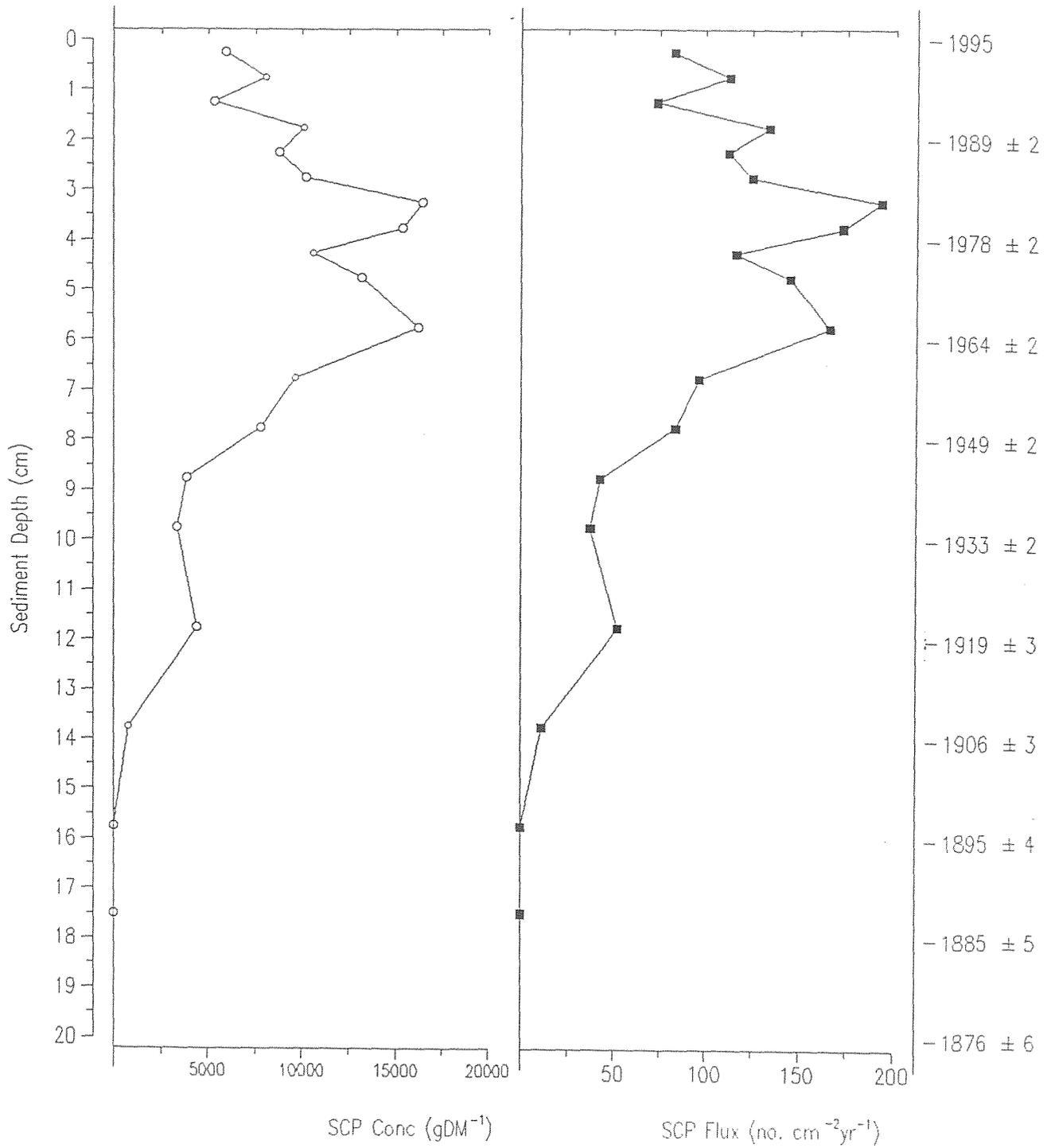


Table 4 SCP data for Loch Laidon 1995 core LAI4.

Depth (cm)	Particles (gDM <sup>-1</sup> )	Flux (cm <sup>-2</sup> yr <sup>-1</sup> )
0.0 - 0.5	5941	83.1
0.5 - 1.0	8060	112.8
1.0 - 1.5	5333	73.3
1.5 - 2.0	10107	133.9
2.0 - 2.5	8797	112.2
2.5 - 3.0	10196	124.9
3.0 - 3.5	16430	193.0
3.5 - 4.0	15337	172.5
4.0 - 4.5	10573	116.3
4.5 - 5.0	13178	145.0
5.5 - 6.0	16176	165.8
6.5 - 7.0	9633	96.3
7.5 - 8.0	7794	83.8
8.5 - 9.0	3893	42.8
9.5 - 10.0	3390	37.3
11.5 - 12.0	4425	52.0
13.5 - 14.0	793	11.5
15.5 - 16.0	0	0
17.0 - 18.0	0	0

Figure 8 SCP concentration and flux profiles for Loch Laidon 1995 core LAI4. Dates are calculated from  $^{210}\text{Pb}$  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  $^{210}\text{Pb}$  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  $0.014 \pm 0.001 \text{ g cm}^{-2} \text{ yr}^{-1}$  ( $0.18 \text{ cm yr}^{-1}$ ). This is very close to the SAR estimated for the 1995 core ( $0.013 \pm 0.001 \text{ g cm}^{-2} \text{ yr}^{-1}$ ). 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  $137 \pm 11$  years old in LAI1 and  $155 \pm 12$  years old in LAI4. These agree to within the uncertainties of the method.

Because of atmospheric radiocaesium contamination, the  $^{137}\text{Cs}$  profiles in LAI1 and LAI4 are markedly different. In the 1995 core LAI4, a major  $^{137}\text{Cs}$  peak of almost  $1200 \text{ Bq kg}^{-1}$  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  $^{137}\text{Cs}$  activities are comparable to those in the 1985 (pre-Chernobyl) LAI1 core.

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

Core	Unsupported $^{210}\text{Pb}$		Weapons $^{137}\text{Cs}$	Sedimentation rate (mean)	
	Inventory $\text{Bq m}^{-2}$	Flux $\text{Bq m}^{-2} \text{ yr}^{-1}$	Inventory $\text{Bq m}^{-2}$	$\text{g cm}^{-2} \text{ yr}^{-1}$	$\text{cm yr}^{-1}$
LAI1 (1985)	7860 $\pm$ 315	245 $\pm$ 10	3150 $\pm$ 100	0.014	0.18
LAI4 (1995)	7730 $\pm$ 190	241 $\pm$ 6	3970 $\pm$ 485	0.013	0.16

### 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 (LAI1) 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 LAI1. Note that only taxa with frequencies greater than 2% are shown. Dates are calculated from  $^{210}\text{Pb}$  measurements. The diagram is re-drawn from Flower *et al.* (1988).

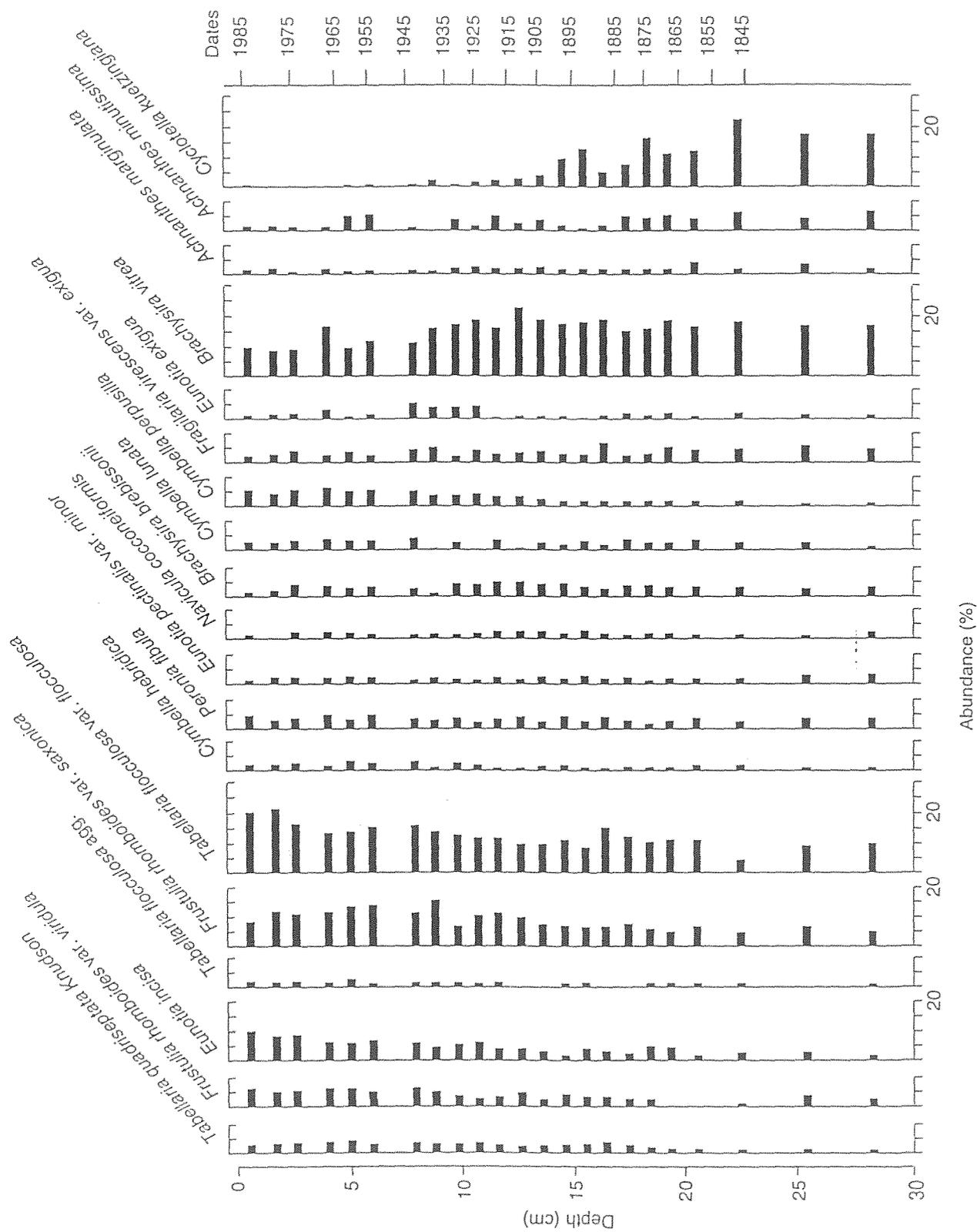


Figure 10 Diatom assemblage diversity as estimated by Hill's N<sub>2</sub> statistic (see text and Hill 1973) for the Loch Laidon 1995 core LAI4 (closed circles) and for the 1985 core LAI1 (open circles). Dates are calculated from <sup>210</sup>Pb measurements.

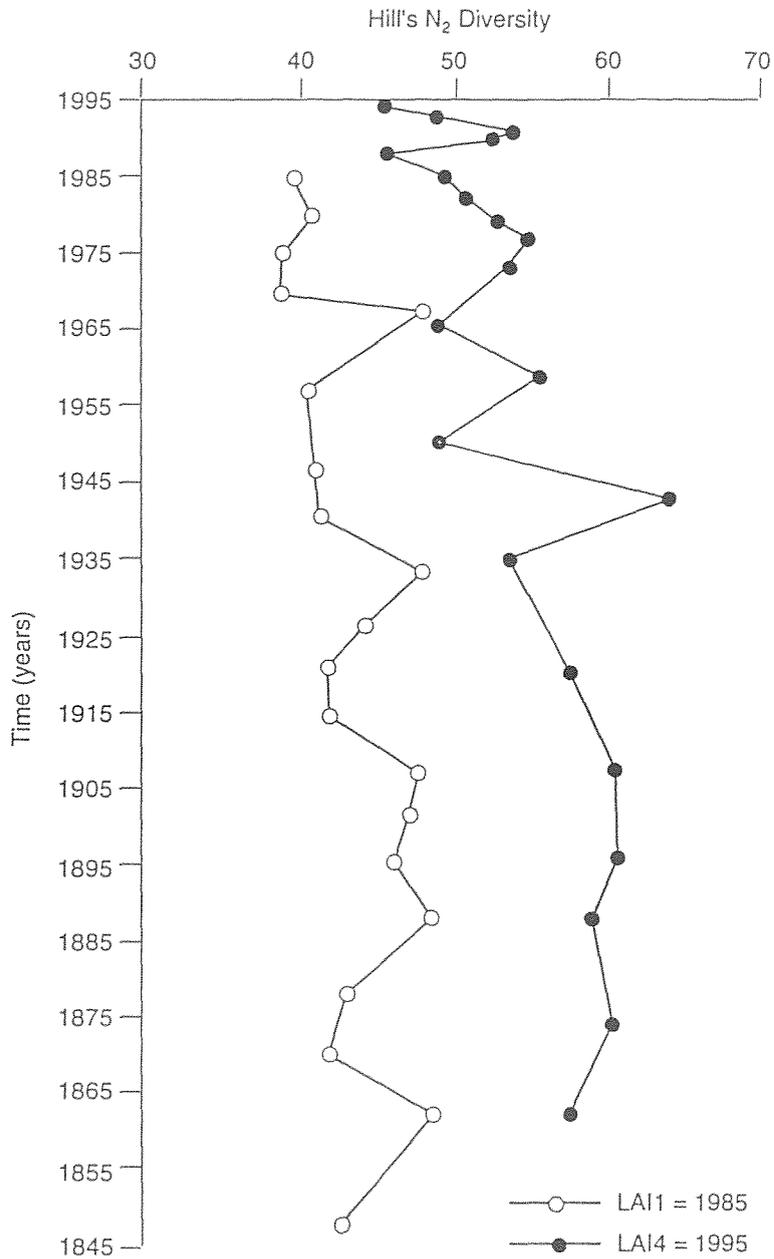


Figure 11 Principal components analysis (PCA) ordination of the sedimentary diatom assemblages in the Loch Laidon 1995 core LAI4 (closed circles) and for the 1985 core LAI1 (open circles). Samples in each core are joined up into time-tracks according to the  $^{210}\text{Pb}$  chronologies. The direction of floristic change is indicated by an arrow.

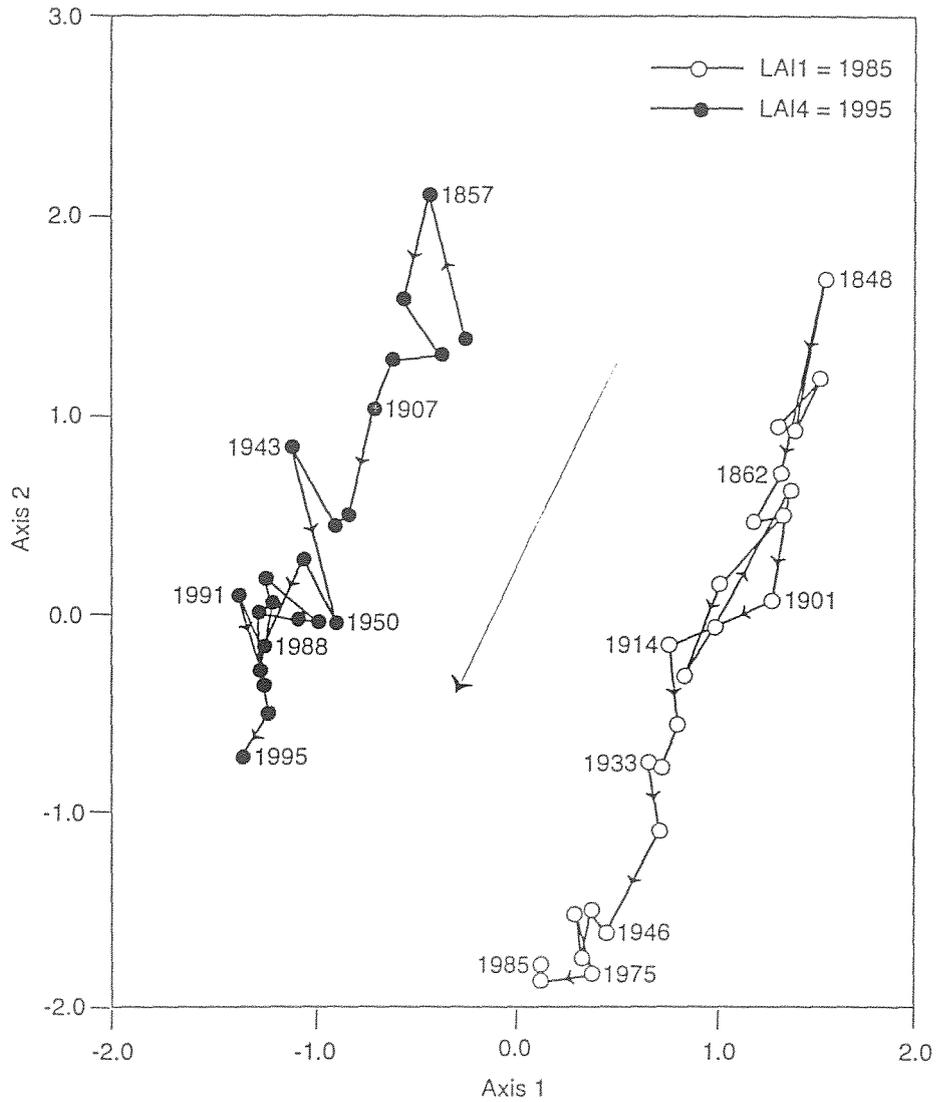


Table 6 SCP data for Loch Laidon 1985 core LAI3.

Depth (cm)	Particles (gDM <sup>-1</sup> )	Flux (cm <sup>-2</sup> yr <sup>-1</sup> )
0.0 - 0.5	8840	137.9
1.0 - 1.5	7840	120.7
2.0 - 2.5	11060	161.5
3.0 - 3.5	5940	82.7
4.0 - 4.5	4960	65.7
5.0 - 5.5	2160	27.5
6.0 - 6.5	1420	17.5
7.0 - 7.5	970	11.6
8.0 - 8.5	490	5.9
9.0 - 9.5	240	2.9
11.0 - 11.5	0	0
12.0 - 12.5	0	0
13.0 - 13.5	0	0
14.0 - 14.5	0	0
15.0 - 15.5	0	0
16.0 - 16.5	130	1.9
17.0 - 17.5	100	1.7
18.0 - 18.5	0	0
19.0 - 19.5	0	0

Figure 12 SCP concentration and flux profiles for Loch Laidon 1985 core LAI3. Dates are calculated from  $^{210}\text{Pb}$  measurements.

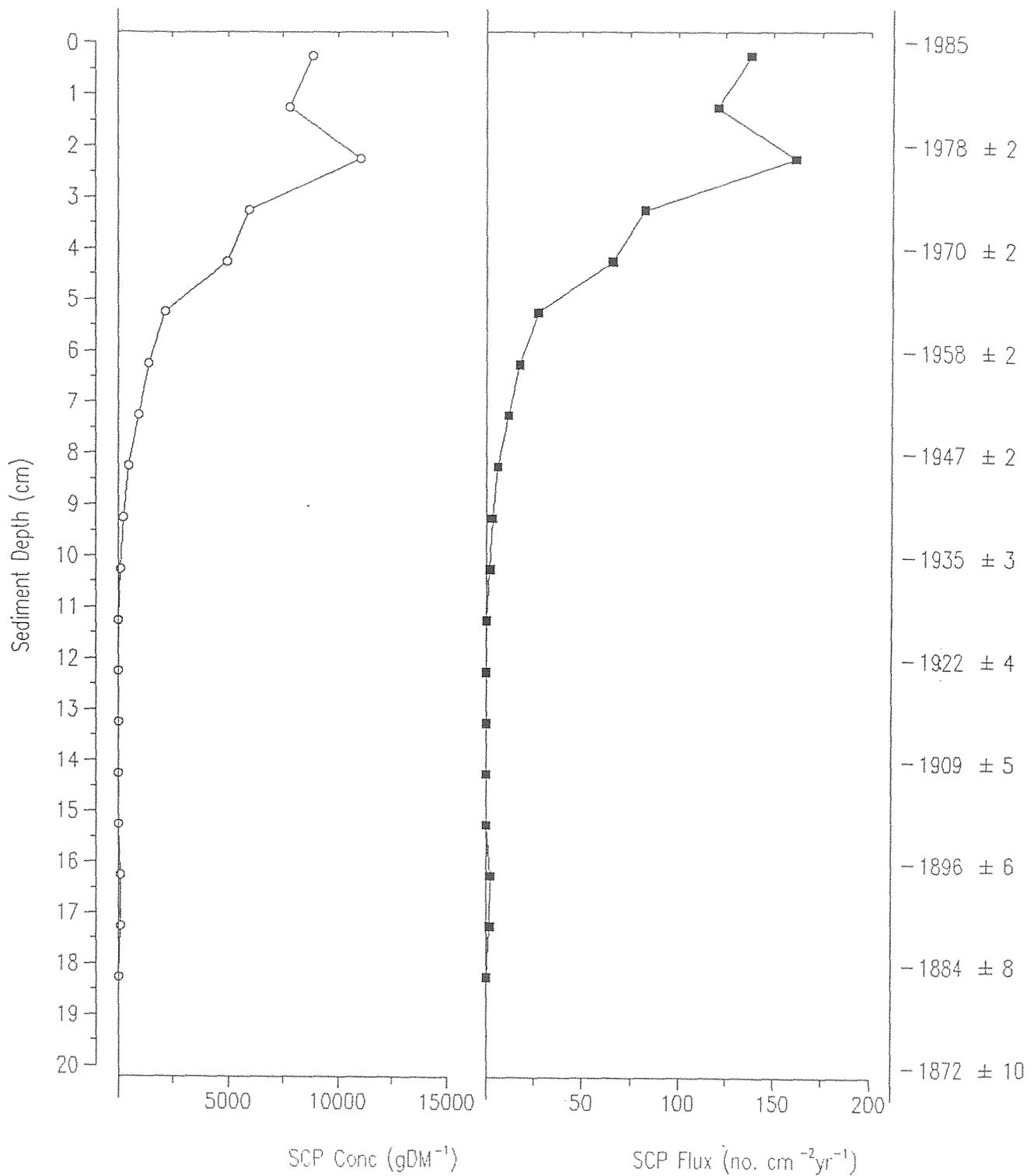
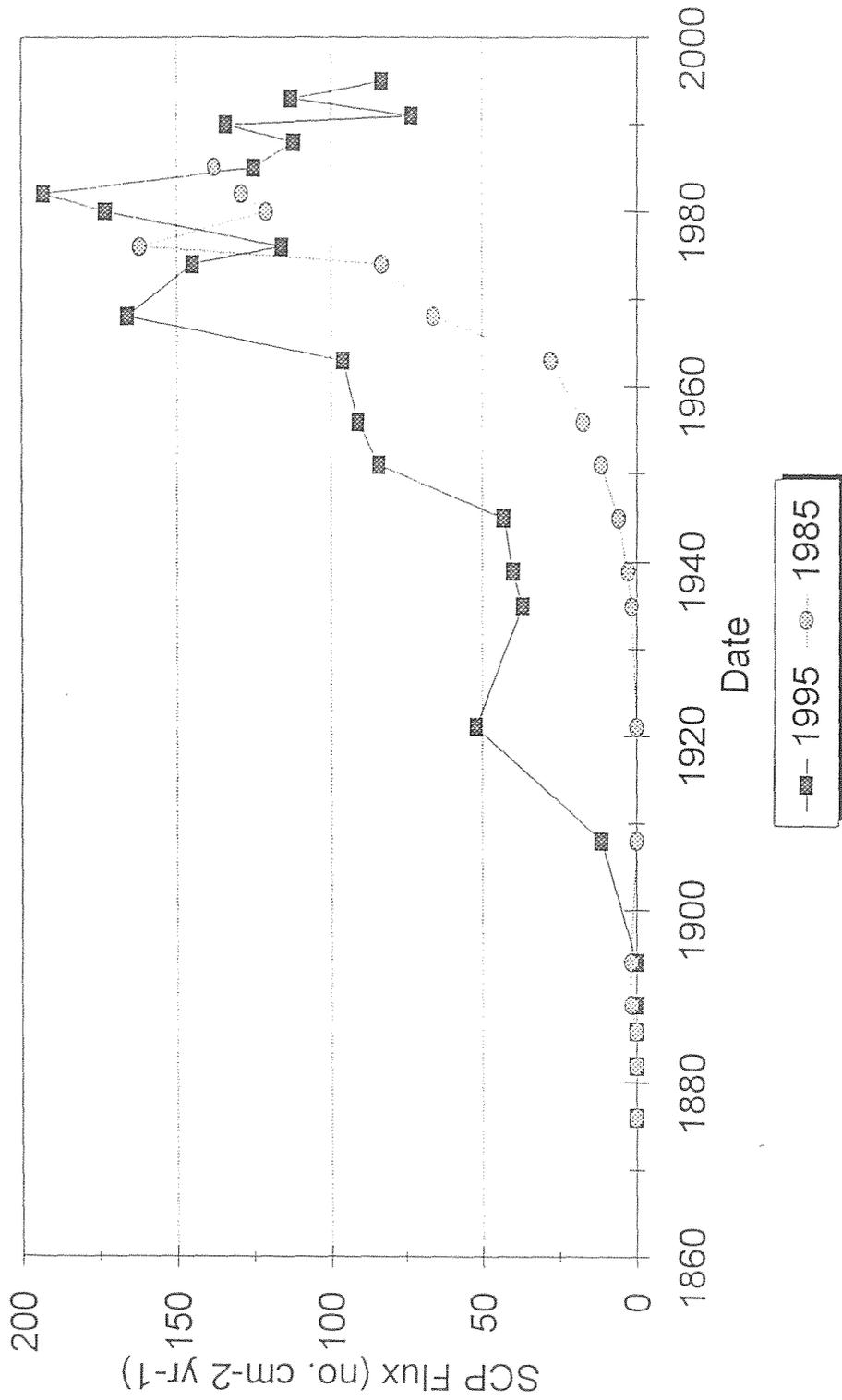


Figure 13 Comparison of SCP flux (accumulation rate) profiles for the Loch Laidon 1995 core LAI4 (squares) and for the 1985 core LAI3 (circles). Dates are calculated from  $^{210}\text{Pb}$  measurements.



## 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.

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## Core LAI1 - 1985

- AC001A *Achnanthes lanceolata* (Breb. ex Kutz.) Grun. in Cleve & Grun. 1880  
 AC002A *Achnanthes linearis* (W. Sm.) Grun. in Cleve & Grun. 1880  
 AC002B *Achnanthes linearis curta* H.L. Sm. ex Boyer 1916  
 AC002C *Achnanthes linearis pusilla* Grun.  
 AC004A *Achnanthes pseudoswazi* J.R. Carter 1963  
 AC009A *Achnanthes recurvata* Hust. 1950  
 AC013A *Achnanthes minutissima* Kutz. 1833  
 AC014A *Achnanthes austriaca* Hust. 1922  
 AC014B *Achnanthes austriaca minor* L. Grannoch (RJF) 1986  
 AC014C *Achnanthes austriaca helvetica* Hust. 1933  
 AC022A *Achnanthes marginulata* Grun. in Cleve & Grun. 1880  
 AC024A *Achnanthes depressa* (Cleve) Hust. 1933  
 AC025A *Achnanthes flexella* (Kutz.) Brun 1880  
 AC028A *Achnanthes saxonica* Krasske in Hust. 1933  
 AC029A *Achnanthes sublaevis* Hust. 1936  
 AC030A *Achnanthes umara* J.R. Carter 1970  
 AC038A *Achnanthes lapponica* (Hust.) Hust. 1933  
 AC044A *Achnanthes levanderi* Hust. 1933  
 AC9999 *Achnanthes* sp.  
 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  
 AU010A *Aulacoseira perglabra*  
 AU010B *Aulacoseira perglabra floriniae*  
 AU014A *Aulacoseira nygaardii* Camburn  
 AU9999 *Aulacoseira* sp.  
 BR001A *Brachysira vitrea* (Grun.) R. Ross in Hartley 1986  
 BR002A *Brachysira follis* (Ehrenb.) R. Ross in Hartley 1986  
 BR003A *Brachysira serians* (Breb. ex Kutz.) Round & Mann 1981  
 BR004A *Brachysira styriaca* (Grun. in Van Heurck) R. Ross in Hartley 1986  
 BR005A *Brachysira zellensis* (Grun.) Round & Mann 1981  
 BR006A *Brachysira brebissonii* R. Ross in Hartley 1986  
 CA002A *Caloneis bacillum* (Grun.) Cleve 1894  
 CM001A *Cymbella ventricosa* Kutz. 1844  
 CM004A *Cymbella microcephala* Grun. in Van Heurck 1880  
 CM009A *Cymbella naviculiformis* Auersw. ex Heib. 1863  
 CM010A *Cymbella perpusilla* A. Cleve 1895  
 CM013A *Cymbella helvetica helvetica* Kutz. 1844  
 CM014A *Cymbella aequalis* W. Sm. ex Grev. 1855  
 CM015A *Cymbella cesatii* (Rabenh.) Grun. in A. Schmidt 1881  
 CM016A *Cymbella amphicephala* Naegeli ex Kutz. 1849  
 CM017A *Cymbella hebridica* (Grun. ex Cleve) Cleve 1894  
 CM019A *Cymbella lacustris* (Ag.) Cleve 1894  
 CM020A *Cymbella gaeumannii* Meister 1934

Core LA11 - 1985

- CM022A *Cymbella affinis* Kutz. 1844  
CM036A *Cymbella obtusa* Greg. 1856  
CM038A *Cymbella delicatula* Kutz. 1849  
CM043A *Cymbella naviculacea* Grun. ex Cleve 1881  
CM048A *Cymbella lunata* W. Sm. in Grev. 1855  
CM9999 *Cymbella* sp.  
CO001A *Cocconeis placentula* Ehrenb. 1838  
CY006A *Cyclotella kuetzingiana* Thwaites 1848  
CY009A *Cyclotella ocellata* Pant. 1902  
DE001A *Denticula tenuis* Kutz. 1844  
DT002A *Diatoma hyemale* (Roth) Heib. 1863  
EU002A *Eunotia pectinalis* (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.  
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 iatriaensis* 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 LAII - 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  
FR9991 Fragilaria [cf. oldenburgiana PIRLA pl 20, 61-2] PIRLA 1987  
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 arentii (Kolbe) Nagumo & Kobayasi 1977  
NA002A Navicula jaernefeltii Hust. 1942  
NA003A Navicula radiosa Kutz. 1844  
NA003B Navicula radiosa tenella (Breb. ex Kutz.) Grun. ex Van Heurck 1885  
NA005A Navicula seminulum Grun. 1860  
NA006A Navicula mediocris Krasske 1932  
NA008A Navicula rhyncocephala Kutz. 1844  
NA013A Navicula pseudoscutiformis 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 Chohn. in Chohn. & 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

### 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 amphirhynchus* (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 sistassa* J.R. Carter 1966  
PI015A *Pinnularia abaujensis* (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 hilseana* 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 *Semiorbis 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.

### Core LA11 - 1985

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

### Core LA14 - 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 floriniae*  
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 cesatii* (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* (Naegeli 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  
EU9951 *Eunotia* [cf. *steineckii*] Hoylandet (RJF) 1988  
EU9961 *Eunotia* [*vanheurckii* var. 1] Round L. Glenhead (RJF) 1988  
EU9964 *Eunotia* [sp. 12 (minor)] L. Grannoch (RJF) 1988  
EU9965 *Eunotia* [sp. 10 (minima)] L. Grannoch (RJF) 1988  
EU9974 *Eunotia* [cf. *meisteri*] Round L (FB-SWAP) 1987  
EU9999 *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 virescens exigua* Grun. in Van Heurck 1881  
FR007A *Fragilaria vaucheriae* (Kutz.) J.B. Petersen 1938  
FR010A *Fragilaria constricta* Ehrenb. 1843  
FR9991 *Fragilaria* [cf. *oldenburgiana* PIRLA pl 20, 61-2] PIRLA 1987  
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 jaernefeltii* Hust. 1942  
NA003B *Navicula radiosa tenella* (Breb. 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

### Core LAI4 - 1995

- 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 cumbriensis* Haworth 1987  
NA160A *Navicula submolesta* Hust. 1949  
NA167A *Navicula hoefleri* 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

### Core LAI4 - 1995

- PI017A *Pinnularia carminata* Barber & J.R. Carter 1978  
PI018A *Pinnularia biceps* Greg. 1856  
PI020A *Pinnularia undulata* Greg. 1854  
PI022A *Pinnularia subcapitata* Greg. 1856  
PI022B *Pinnularia subcapitata hilseana* (Janisch ex Rabenh.) O. Mull. 1898  
PI023A *Pinnularia irrorata* (Grun. in Van Heurck) Hust. 1939  
PI024A *Pinnularia stomatophora* (Grun. ex A. Schmidt) Cleve 1891  
PI026A *Pinnularia tenuis* Gregory  
PI030A *Pinnularia acoricola* Hust.  
PI051A *Pinnularia lata* (Breb.) W. Sm. 1853  
PI170A *Pinnularia braunii* (Grun.) Cleve  
PI9995 *Pinnularia* [cf. *angulata*] L. Valley (RJF) 1984  
PI9999 *Pinnularia* sp.  
SA001A *Stauroneis anceps* Ehrenb. 1843  
SA001B *Stauroneis anceps gracilis* Rabenh. 1864  
SA005A *Stauroneis legumen* (Ehrenb.) Kutz. 1844  
SA9999 *Stauroneis* sp.  
SE001A *Semiorbis hemicyclus* (Ehrenb.) Patr. in Patr. & Reimer 1966  
SP002A *Stenopterobia sigmatella* (Greg.) R. Ross in Hartley 1986  
SP9999 *Stenopterobia* sp.  
SU004A *Surirella biseriata* Breb. & Godey 1835  
SU005A *Surirella linearis linearis* W. Sm. 1853  
SU006A *Surirella delicatissima* Lewis 1864  
SU016A *Surirella minuta* Breb. ex Kutz. 1849  
SU9999 *Surirella* sp.  
SY002A *Synedra rumpens* Kutz. 1844  
SY003A *Synedra acus* Kutz. 1844  
SY010A *Synedra minuscula* Grun. in Van Heurck 1888  
SY9999 *Synedra* sp.  
TA001A *Tabellaria flocculosa* (Roth) Kutz. 1844  
TA001B *Tabellaria flocculosa* IIIp *flocculosa* Koppen  
TA003B *Tabellaria binalis elliptica* Flower 1986  
TA004A *Tabellaria quadriseptata* Knudson 1952