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Using novel palaeolimnological techniques to define lake conservation objectives (Phase 1)

Final Report to Natural England

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Executive summary

This is the final report to Natural England on Contract No: SAE03/02/054 'Using novel palaeolimnological techniques to define lake conservation objectives'.

The primary objective of this project is to use existing and recently developed palaeoecological techniques to define reference conditions and assess the condition of selected SSSIs in England, and thereby to assist in the setting of conservation objectives and management goals. The eight selected sites are Aqualate Mere, Hawes Water (Silverdale), Cunswick Tarn, Over Water, Sunbiggin Tarn, Malham Tarn, Semer Water and Hornsea Mere. The project is divided into four main tasks with Task 1 essentially involving the collection, processing and dating of cores from the study sites. To date only the latter has been funded and this report describes the outputs of this task.

A single sediment core was collected from eight sites during the period 14-21 January 2008 using a wide-diameter (~8 cm) Livingstone type piston coring device. The cores varied in length from 0.74 to 1.35 m.

The cores were extruded in the field or the laboratory at 1 cm intervals to provide a resolution of approximately a few years per sample, and any visible stratigraphic changes were noted.

The percentage dry weight which gives a measure of the water content of the sediment, the percentage loss on ignition which gives a measure of the organic matter content and the percentage carbonate were measured on selected sub-samples from each core.

Dating of the cores was carried out using the well established technique of spheroidal carbonaceous particle (SCP) analyses. Cores from Cunswick Tarn, Over Water, Sunbiggin Tarn, Malham Tarn and Hornsea Mere all exhibited typical features of SCP profiles for UK lakes and therefore a chronology could be derived for these five sites. However, additional samples will be analysed from Sunbiggin Tarn and Hornsea Mere in an attempt to provide more robust dates. At Aqualate Mere, the SCP record was somewhat irregular and appeared to be truncated but nonetheless several dates could be derived. The SCP profiles for Hawes Water and Semer Water were highly irregular and therefore a reliable chronology could not be obtained for these two sites.

Sub-samples at 2 cm intervals from each core have been frozen for potential future pigment analyses at University of Nottingham. The remaining samples are currently in cold storage at UCL and it is anticipated that a second phase of the project will involve analyses of biological remains in selected levels to define reference conditions and assess recent ecological change.

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Cover photograph: Hawes Water, Silverdale (January 2008).

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SPECIFICATION

Statement of understanding, purpose and aims of project

The primary objective of this project is to use existing and recently developed palaeoecological techniques to define reference conditions and assess the condition of selected SSSIs in England, and thereby to assist in the setting of conservation objectives and management goals. The eight selected sites are Aqualate Mere, Hawes Water (Silverdale), Cunswick Tarn, Over Water, Sunbiggin Tarn, Malham Tarn, Semer Water and Hornsea Mere.

The project is divided into four main tasks with Task 1 essentially involving the collection, processing and dating of cores from the study sites. Tasks 2 to 4 each have their own objective with Task 2 to focus on three lakes where new palaeolimnological studies are required to help define conservation objectives, Task 3 to employ macrofossil studies at five marl systems to determine reference conditions and ecological change, and Task 4 to provide a detailed multi-proxy analysis at one selected site to demonstrate the value of the approach for understanding shifts in ecological structure and function and for setting ecosystem reference conditions.

To date only Task 1 has been funded and this report describes the outputs of this task.

In summary, Task 1 involves:

1. Collection of a long (~1 m) sediment core from each of eight selected sites
2. Sub-sampling and standard sediment analysis (% dry weight, % organic matter)
3. Spheroidal carbonaceous particle analyses to provide a chronology for approximately the last 150 years for each core.

The results are presented for each site.

Sub-samples at 2 cm intervals from each core have been frozen for potential future pigment analyses at University of Nottingham. The remaining samples are currently in cold storage at UCL and it is anticipated that a second phase of the project will involve analyses of biological remains in selected levels to define reference conditions and assess recent ecological change.

METHODS

Core collection

A single sediment core was collected from the eight selected sites during the period 14-21 January 2008 using a wide-diameter (~8 cm) Livingstone type piston coring device. The cores varied in length from 0.74 to 1.35 m and were expected to represent approximately the last 100-150 years, thereby allowing reference conditions to be defined and recent ecological change to be assessed. Expert judgement and any previous data on sediment distribution were used to decide on the optimal coring location that maximises the likelihood of obtaining a sound chronology and finding abundant remains of the fossil groups of interest, particularly plant macrofossils. All cores were taken from shallow water areas within 100 m distance from the shore and locations were recorded by GPS. Summary details of the cores are given in Table 1.

Extrusion, core description and stratigraphic analyses

The cores were extruded in the field or the laboratory at 1 cm intervals to provide a resolution of approximately a few years per sample, and any visible stratigraphic changes were noted (Table 1). All cores have been entered onto our in-house AMPHORA database and are currently being stored in a dedicated cold room in the Geography Department laboratories, pending future analyses. The percentage dry weight (DW) which gives a measure of the water content of the sediment, the percentage loss on ignition (LOI 550) which gives a measure of the organic matter content, and the percentage carbonate content (LOI 950) was undertaken using standard techniques (Dean, 1974; Heiri *et al.,* 2001) on selected sub-samples from each core. Sub-samples at 2 cm intervals from each core have been frozen for potential future pigment analyses at University of Nottingham.

Dating

Dating of the cores from the eight sites was carried out using the well established technique of spheroidal carbonaceous particle (SCP) (Rose, 1994). Dried sediment was subjected to sequential chemical attack by mineral acids to remove unwanted fractions leaving a suspension of mainly carbonaceous material and a few persistent minerals in water. SCPs are composed mostly of elemental carbon and are chemically robust. The use of concentrated nitric acid (to remove organic material), hydrofluoric acid (siliceous material) and hydrochloric acid (carbonates and bicarbonates) therefore does them no damage. A known fraction of the resulting suspension was evaporated onto a coverslip and mounted onto a microscope slide. The number of SCPs on the coverslip was counted using a light microscope at x400 magnification and the sediment concentration calculated in units of 'number of particles per gram dry mass of sediment' (gDM^{-1}). The criteria for SCP identification under the light microscope followed Rose (2008). Analytical blanks and SCP reference material (Rose, 2008) were included in each batch of sample digestions. Reference concentrations agreed with the expected values while no SCPs were observed in the blanks. The detection limit for the technique is ~100 gDM^{-1} and concentrations have an accuracy of ~ ± 45 gDM^{-1}.

The analysis of the cores was completed in two stages. First, a 'skeleton' profile covering the length of the core was produced and then, after this initial analysis was completed, a second stage of 'filling-in' was undertaken. This approach allows a more targeted analysis and is able to focus on the area of the sediment cores containing the SCP profile.

The dating of the cores followed the method described in Rose *et al*. (1995) whereby three main features of the SCP profile are used to provide dates. A later approach

using cumulative SCP inventory profiles (Rose & Appleby, 2005) is less applicable to littoral cores. This is because the method requires that a full record be present so that percentiles from the cumulative curve can each be ascribed a date. This is not possible where the record is incomplete. Sediment accumulation in littoral cores is not always as consistent as in deeper waters and hence application of the cumulative approach may lead to erroneous dates being applied. Hence in these cores the former method, although providing fewer dates for each core, was considered to be more reliable.

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

Site name	WBID	Lake NGR	Alt (m)	Area (ha)	Max depth (m)	Core code	Sampleid	Coring date	Core type	Coring location	Core length (m)	Coring water depth (m)	Approx distance from shore (m)	Secchi depth-Jan08 (m)
Aqualate Mere	35724	SJ 772 204	67	75.3	< 1	AQUA3	509367	14-Jan-08	Fat piston	SJ 77484 20188	0.86	1.3	40	0.3
Hawes Water	29647	SD 477 766	8	5.7	12	HAWE2	509361	15-Jan-08	Fat piston	SD 47872 76670	0.79	2.6	2	7.0
Cunswick Tarn	29394	SD 489 937	138	0.8	?	CUNS1	509086	16-Jan-08	Fat piston	SD 48943 93728	0.74	2.4	10	2.7
Over Water	28806	NY 251 350	188	19.7	8	OVER1	509362	17-Jan-08	Fat piston	NY 25069 34884	1.35	2.8	20	2.2
Sunbiggin Tarn	29178	NY 676 076	255	3.7	11	SUNB3	509363	19-Jan-08	Fat piston	NY 67566 07611	1.35	2.3	15	2.0
Semer Water	29479	SD 919 872	246	28.6	12	SEME3	509364	19-Jan-08	Fat piston	SD 91846 87326	0.91	2.95	20	0.45
Malham Tarn	29844	SD 893 667	375	60	4.4	MALH4	509365	20-Jan-08	Fat piston	SD 89145 67039	1.18	2	100	>2
Hornsea Mere	30244	TA 190 469	8	133.3	< 2	HORN3	509366	21-Jan-08	Fat piston	TA 19148 47477	1.32	1.75	20	0.5

AQUALATE MERE

Core description

A piston core, 0.86 m in length, was collected from Aqualate Mere on 14-Jan-08 in 1.3 m water depth, approximately 40 m from the southern shore. At the time of coring, the water level was high and the lake was turbid (secchi depth 0.3 m) and orange-brown in colour.

The core had two distinct horizons (Figure 1). The upper 28 cm of the core was mid-brown in colour and was comprised of an odourless, silt-clay which may be in-washed material from the canal. The section from 28 to 73 cm was a dark brown, fine lake material with odour. The section below 73 cm to the core base was also a dark brown, fine lake mud but was denser than the upper core with abundant fossil remains, especially molluscs. There was a general increase in the numbers of mollluscs downcore. The very bottom of the core was comprised of peat with abundant molluscs suggesting that the entire lacustrine sequence was recovered by the core.

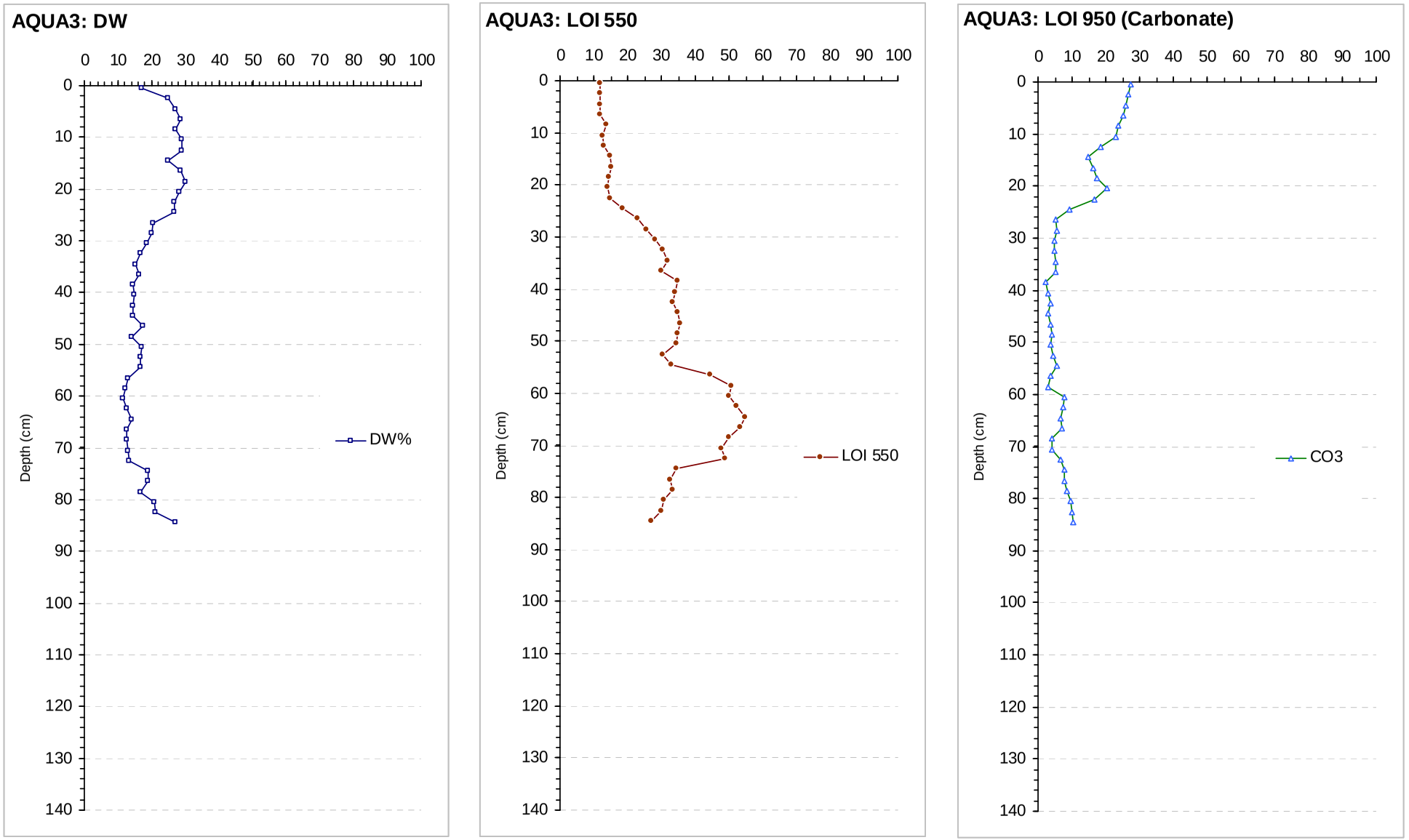
Figure 1 Sediment core stratigraphy of AQUA3

Depth (cm)	Sediment colour
0-28	Mid-brown
28-73	Dark brown
73-85	Dark brown (abundant molluscs)
85-86	Peat (abundant molluscs)

Stratigraphic analyses

The core, AQUA3, was relatively dense but organic in the lowermost section below ~73 cm with LOI 550 values of ~30% (Figure 2). Above this was a highly organic layer extending from ~58-73 cm with LOI 550 values of ~50%. Subsequently, the organic matter content gradually declines upwards through the core before stabilising at low LOI 550 values of 10-15% in the upper 25 cm. The uppermost 25 cm has relatively high DW values of 25-30% and higher percentage carbonate than the lower core with LOI 950 values reaching a maximum of 27% at the surface.

Figure 2 Stratigraphic data for AQUA3



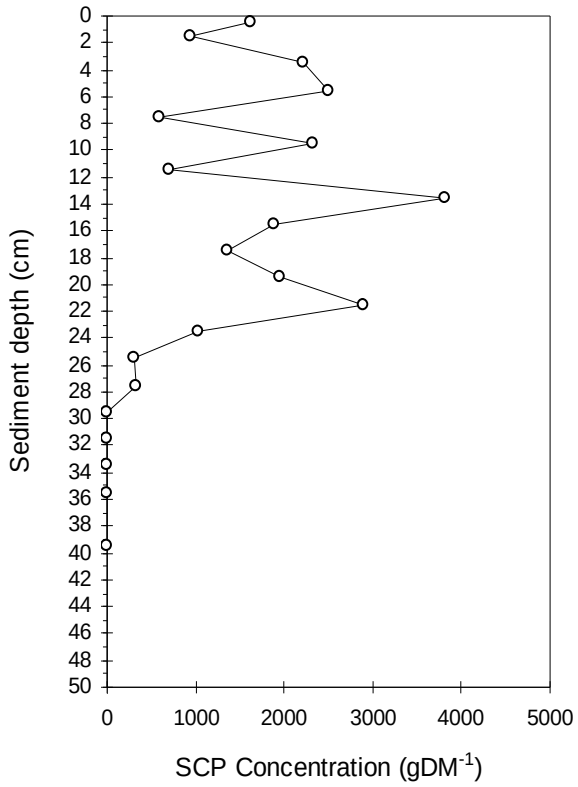
Spheroidal carbonaceous particle analysis

The SCP profile from AQUA3 is rather irregular with a series of peaks and troughs throughout (Table 2, Figure 3). The first presence of SCPs occurs at 27-28 cm while the peak concentration of almost 4000 gDM^{-1} occurs at 13-14cm. It seems likely that this SCP profile does not represent the full industrial record of deposition since 1850, but rather is truncated at a point where SCP concentrations fall below the analytical detection limit. This is quite common in sediment cores of rapid accumulation or where sediment accumulation is less consistent.

Table 2 SCP concentrations for AQUA3

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	1619	600
1.5	944	534
3.5	2211	969
5.5	2507	929
7.5	589	408
9.5	2321	928
11.5	691	479
13.5	3813	1036
15.5	1893	927
17.5	1362	597
19.5	1958	858
21.5	2897	856
23.5	1026	581
25.5	315	309
27.5	327	321
29.5	0	0
31.5	0	0
33.5	0	0
35.5	0	0
39.5	0	0
59.5	0	0
79.5	0	0

Figure 3 SCP profile for AQUA3



Although the peak concentration is represented only by a single data point, it is clearly higher than any other point on the profile. If we assume that this is the maximum concentration then we can ascribe this the date of 1978 ± 4. Given the sampling resolution this peak could lie between 12 and 15 cm which would provide a mean sediment accumulation rate of 0.4-0.5 cm yr^{-1} for the post-1978 period. Extrapolating this rate would place 1950, the time at which a rapid increase in SCP concentration is usually observed, between 23.5 and 29 cm. The profile would suggest that this feature occurs at ~25 cm indicating a good agreement and suggesting that the sediment accumulation rate in this core is reasonably consistent over the last 50-60 years. This would also imply that the profile is truncated at around this time and that the start of the record occurs where the SCP concentration exceeds the analytical detection limit for the first time as a result of the rapidly increasing deposition of SCPs in the 1950s (Rose *et al*., 1995). Although it is not possible to provide any further dates below this time from the SCP record this rate would place 1850 between 63 and 79 cm depth. The best available chronology is summarised in Table 3.

Table 3 The SCP derived chronology for AQUA3

Sediment depth (cm)	Age (Years)	Date
0	0	2008
5	11 ± 2	1997 ± 2
10	23 ± 3	1985 ± 3
15	34 ± 4	1974 ± 4
20	45 ± 5	1963± 5
25	56 ± 8	1952 ± 8
30	68 ± 10	1940 ± 10

HAWES WATER

Core description

A piston core, 0.79 m in length, was collected from Hawes Water on 15-Jan-08 in 2.6 m water, approximately 2 m from the shoreline. The coring location was beyond a steep shelf of *Chara aculeolata* and *Potamogeton coloratus* and into *Nymphaea* beds on the east side of lake. Marginal plants included *Cladium, Phragmites* and *Typha angustifolia*.

The core had several clear bands (Figure 4). The upper 10 cm was dark grey marl with the section from 10-26 cm being lighter grey in colour. There was a very light grey band at 26-31 cm followed by a return to a light grey marl from 31-53 cm. At 53-59 cm there was another very light grey band with abundant molluscs and slightly coarser grain size before returning to light grey marl with fewer molluscs from 59-62 cm. At 62-66 cm the sediment was dark brown-grey and was rich in molluscs, followed by light grey marl again from 66-77 cm with abundant molluscs and *Chara* encrustations, and a sulphurous odour. The last section from 77-79 cm was mid-brown in colour and sulphurous, and also contained abundant *Chara* encrustations. The core was markedly different from another core taken at SD 47698 76651 on the west side of lake which was dark brown in colour throughout.

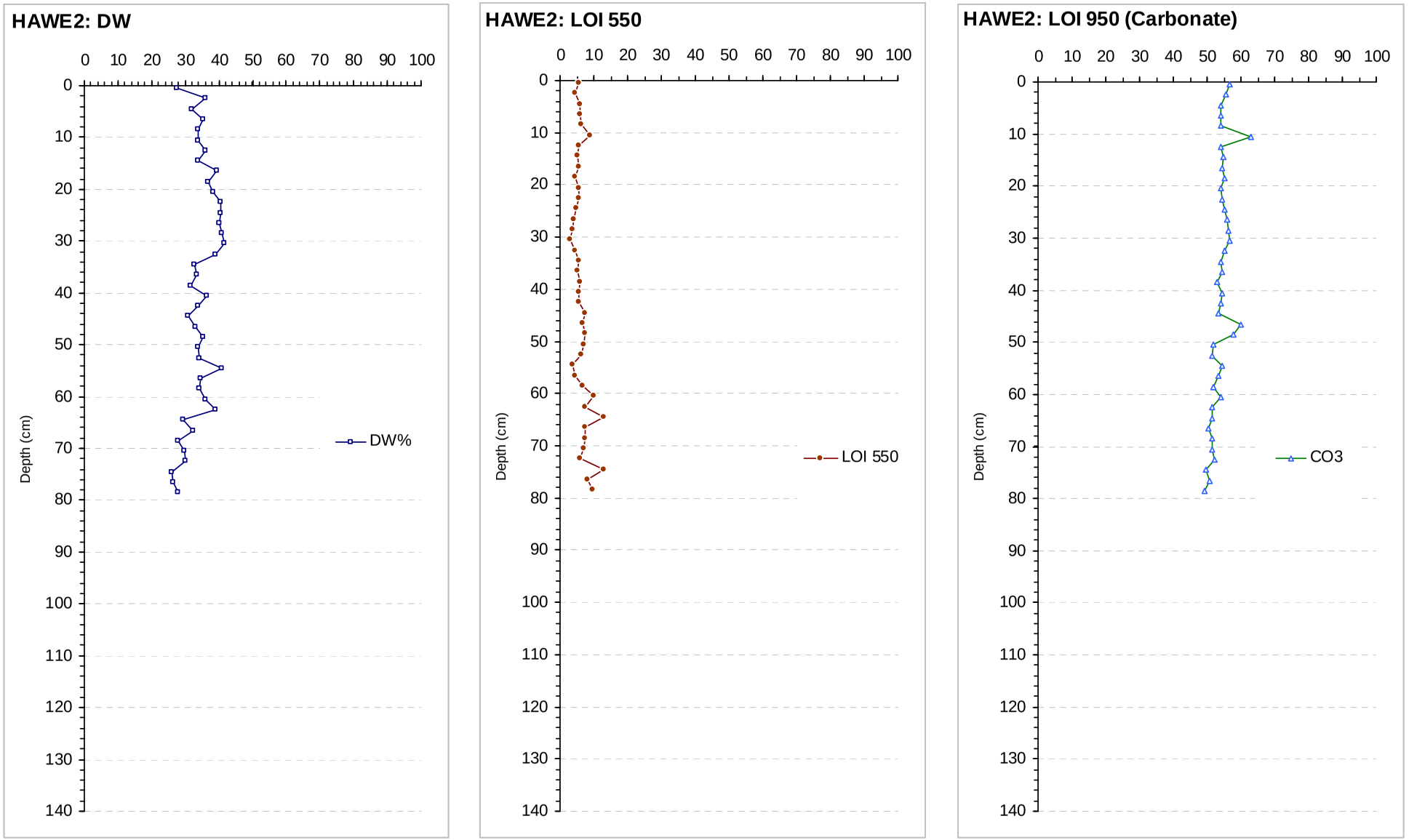
Figure 4 Sediment core stratigraphy of HAWE2

Depth (cm)	Sediment colour
0-10	Dark grey
10-26	Light grey
26-31	Very light grey
31-53	Light grey
53-59	Very light grey
59-62	Light grey
62-66	Dark brown-grey
66-77	Light grey
77-79	Mid-brown

Stratigraphic analyses

The core, HAWE2, was low in organic matter (LOI 550 <10%) and high in carbonate (LOI 950 >50%) throughout with only minor fluctuations in sediment composition (Figure 5). This reflects the carbonate rich nature of the deposits in this marl system.

Figure 5 Stratigraphic data for HAWE2



Spheroidal carbonaceous particle analysis

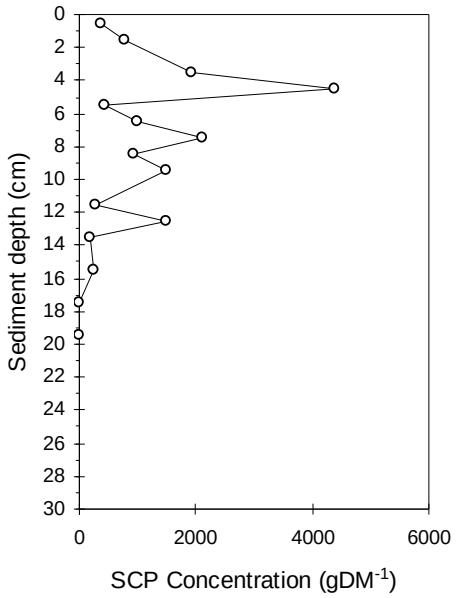
The SCP profile from HAWE2 appears irregular with a series of peaks and troughs (Table 4, Figure 6). The first presence of SCPs occurs at 15-16 cm while a clearly defined peak concentration of over 4300 gDM^{-1} occurs at 4-5 cm. As sampling at this point is contiguous we can ascribe the date of 1978 ± 2 to 4-5 cm with reasonable confidence. This indicates a mean sediment accumulation rate over the last 30 years of 0.15 cm yr^{-1}.

The rapid increase feature is not obvious and extrapolation of the uppermost sediment accumulation rate would place 1950 at 8-9 cm where no feature representing this appears to occur. If the first presence of SCPs at 15-16 cm represents 1850 then the sediment accumulation rate has doubled in recent decades. While that is quite possible, it seems more likely that the full SCP record is not present in HAWE2 and that it is truncated at some unidentified point in time. Without a rapid increase feature to refine the dating we are unable to estimate when this might have occurred. The best available chronology is therefore that 4-5 cm represents 1978 ± 2 and that the core above 16 cm is post -1850.

Table 4 SCP concentrations for HAWE2

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	367	726
1.5	776	1064
3.5	1925	2470
4.5	4370	5884
5.5	440	871
6.5	983	1946
7.5	2099	2827
8.5	942	1355
9.5	1491	2221
11.5	285	564
12.5	1486	2081
13.5	189	375
15.5	256	507
17.5	0	0
19.5	0	0
39.5	0	0
59.5	0	0

Figure 6 SCP profile for HAWE2



CUNSWICK TARN

Core description

A piston core, 0.74 m in length, was collected from Cunswick Tarn on 16-Jan-08 in 2.4 m water, approximately 10 m from the shore on the west side of the lake. Marginal vegetation included *Phragmites, Salix, Alnus*, and beds of *Nuphar lutea*. Fragments of *Elodea canadensis* and a fine-leaved *Potamogeton* (probably *berchtoldii*) were also seen during coring. The lake is used for wildfowl shooting and has several hides and feeders. There was evidence of trampling and reed cutting.

The core had several visible stratigraphic horizons (Figure 7). The upper 17 cm was dark brown with very few molluscs but the 9-10 cm sample was notably full of root remains. The section from 17-32 cm was also dark brown but contained more molluscs than the upper core. The section 32-55 cm was light brown with abundant molluscs and *Chara* encrustations. A light grey band seen in the tube at 40-44 cm was not visible when extruding. The lowermost section from 55-74 cm was mid-brown but molluscs were absent and the *Chara* encrustations disappeared. The basal sample was dense with high clay content and contained fibrous root material.

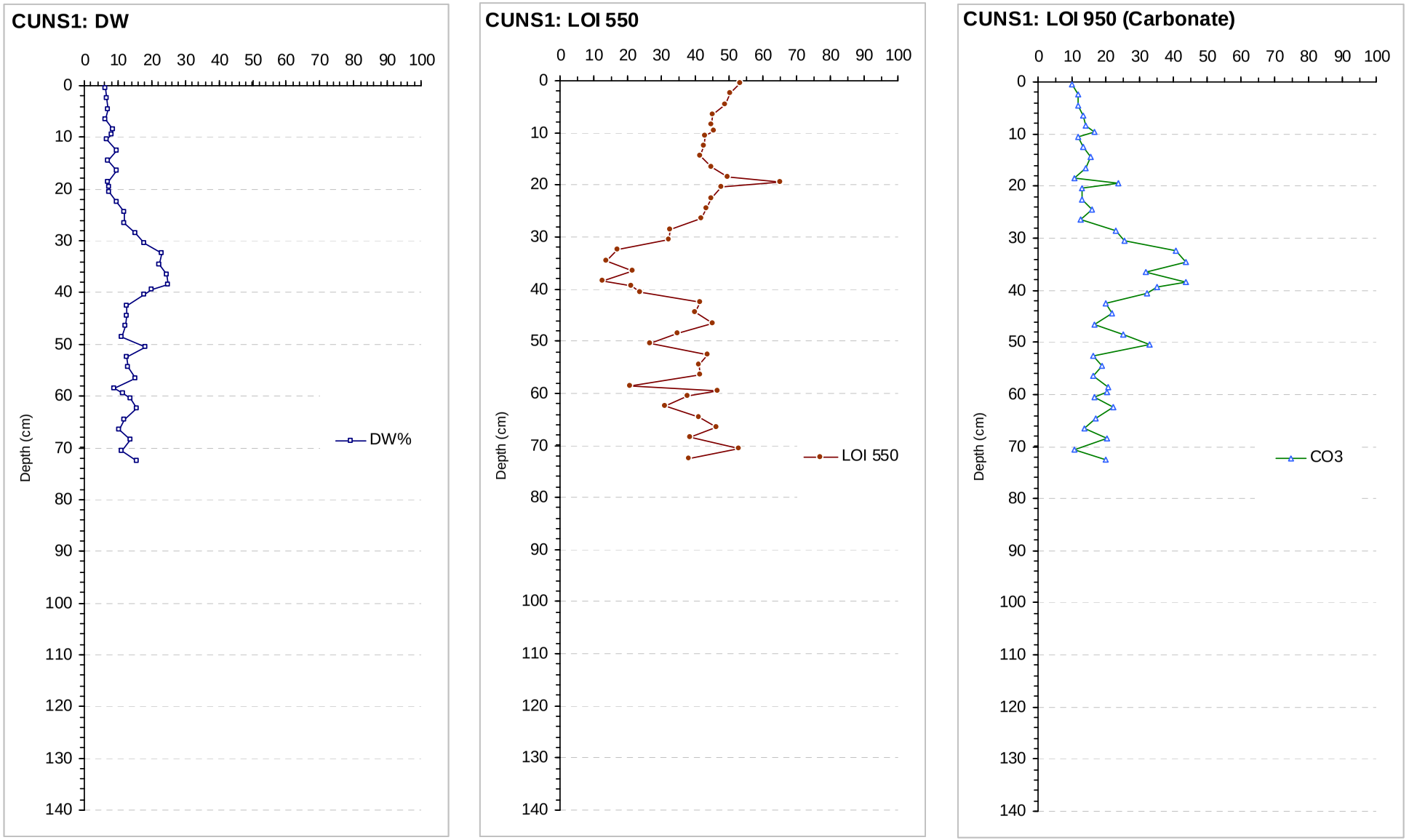
Figure 7 Sediment core stratigraphy of CUNS1

Depth (cm)	Sediment colour
0-17	Dark brown (few molluscs)
17-32	Dark brown (abundant molluscs)
32-40	Light brown (abundant molluscs and *Chara* encrustations)
40-44	Light grey
44-55	Light brown (abundant molluscs and *Chara* encrustations)
55-74	Mid-brown (molluscs absent, few *Chara* encrustations)

Stratigraphic analyses

The core, CUNS1, was organic in the lower section below ~40 cm with LOI 550 values of ~40-50% (Figure 8). Above this was a denser, carbonate rich layer extending from ~32-40 cm with LOI 950 values of ~40%, coincident with the section in which abundant molluscs and *Chara* encrustations were observed during extrusion. In the upper 30 cm of the core, LOI 550 increased gradually to a maximum of ~65% at 20 cm before declining to values of ~40-50% in the uppermost section. Both DW and LOI 950 exhibited a general decrease in the upper 30 cm to values of less than 10%, highlighting the organic nature of the upper core.

Figure 8 Stratigraphic data for CUNS1



Spheroidal carbonaceous particle analysis

The SCP profile from CUNS1 shows a typical SCP profile with clearly defined peak and rapid increase features (Table 5, Figure 9). The first presence of SCPs occurs at 39-40 cm while the peak concentration of 7400 gDM^{-1} occurs at 7-8 cm. As sampling resolution at this point is reasonably good we can ascribe the date of 1978 ± 2 to 7-8 cm with reasonable confidence. This indicates a mean sediment accumulation rate over the last 30 years of 0.25 cm yr^{-1}. However, extrapolation of this rate would place 1950 at 14-15cm but the feature appears to fall below this depth at 17-19 cm. This indicates that sediment accumulation has not been consistent. If 1950 is ascribed to 17-19 cm then this suggests a mean sediment accumulation rate of 0.34-0.41 cm yr^{-1} for the period 1950-1978. If the first presence of SCPs at 39-40 cm represents 1850 then the mean sediment accumulation rate between 1850 and 1950 is ~0.215 cm yr^{-1}. This is slightly less than the rate over the most recent 30 years and suggests a probable gradual increase in sediment accumulation rate over the last ~150 years with a period of more rapid accumulation in the 1950s and 1960s (Table 6).

Table 5 SCP concentrations for CUNS1

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	1600	784
1.5	1764	864
3.5	5839	1587
5.5	5675	1605
7.5	7400	1938
9.5	5500	1348
11.5	5409	1417
13.5	5656	1431
15.5	3513	1217
17.5	3779	1400
19.5	1421	696
21.5	1928	945
25.5	1200	679
29.5	643	445
33.5	357	350
37.5	0	0
39.5	874	605
41.5	0	0
45.5	0	0
49.5	0	0
53.5	0	0
57.5	0	0

Figure 9 SCP profile for CUNS1

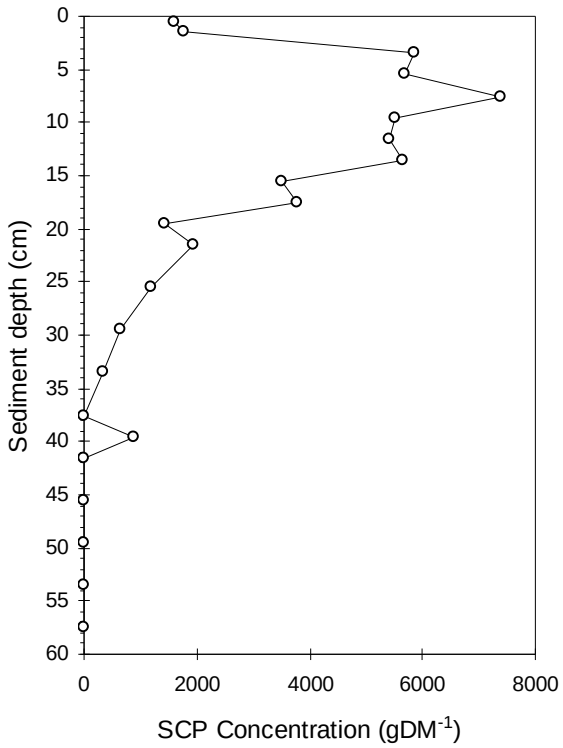


Table 6 The SCP derived chronology for CUNS1

Sediment depth (cm)	Age (Years)	Date
0	0	2008
5	20 ± 2	1988 ± 2
10	37 ± 3	1971 ± 3
15	51 ± 4	1957 ± 5
20	64 ± 8	1944± 8
25	87 ± 10	1921± 10
30	110 ± 15	1898 ± 15
35	133 ± 20	1875 ± 20
40	155 ± 25	1853 ± 25

OVER WATER

Core description

A piston core, 1.35 m in length, was collected from Over Water on 17-Jan-08 in 2.8 m water, approximately 20 m from the shore on the west side of the lake. Marginal vegetation was comprised principally of *Phragmites* and the submerged taxa *Callitriche hamulata* and *Elodea canadensis* were observed during sampling.

The core had two distinct horizons (Figure 10). The upper 80 cm was grey-brown and the section below 80 cm was dark grey and was more consolidated with higher clay content. Two slightly paler layers were observed whilst extruding at ~27 cm and ~97 cm, although these were not clearly visible when the core was in the tube. *Chara* encrustations were abundant at 127-128 cm.

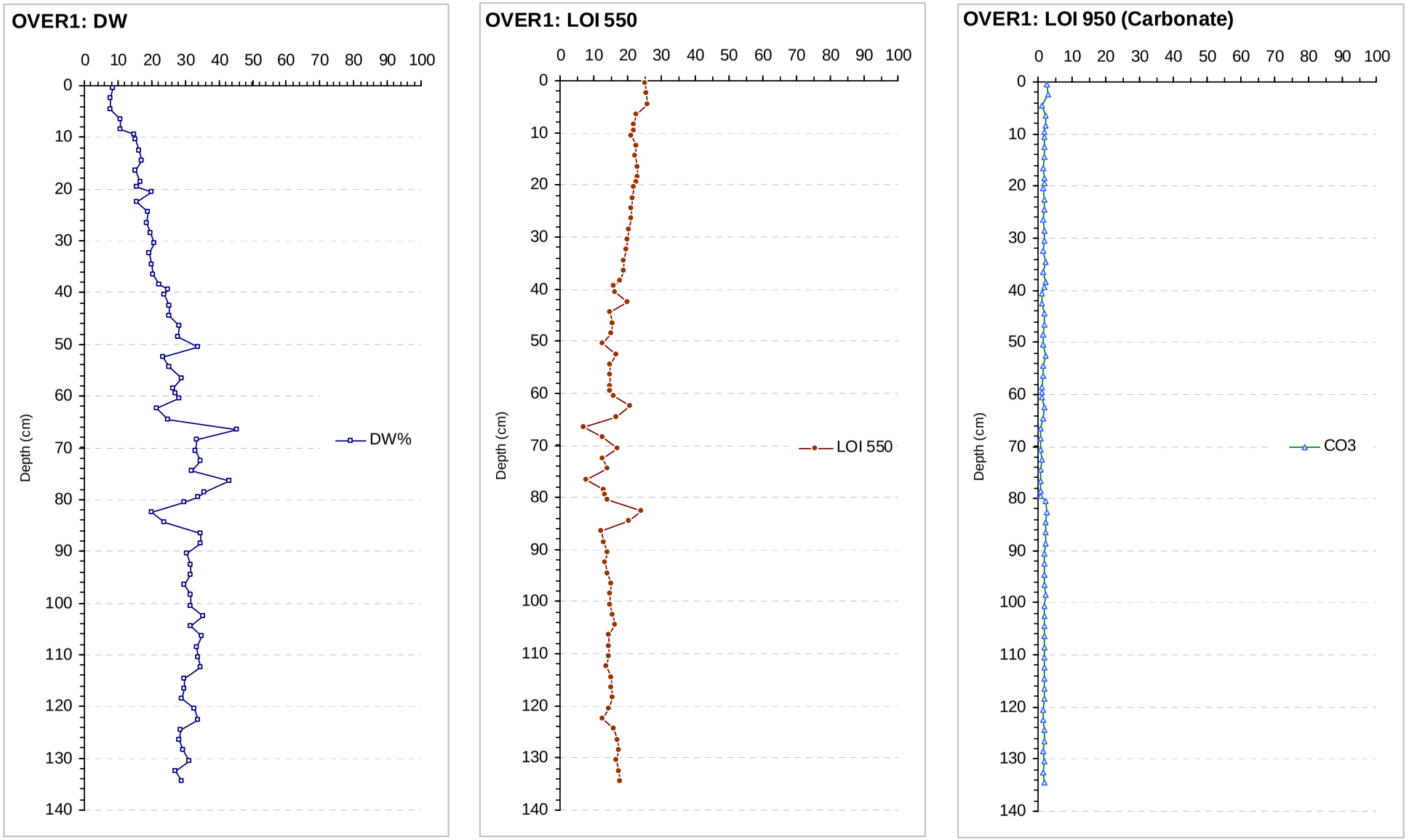
Figure 10 Sediment core stratigraphy of OVER1

Depth (cm)	Sediment colour
0-80	Grey-brown
80-135	Dark grey

Stratigraphic analyses

The core, OVER1, was relatively inorganic and had low carbonate content (<3%) throughout. LOI 550 values in the lower section, below ~65 cm, were 15% whilst DW values were reasonably high at ~30-40% (Figure 11). Above this the sediment became gradually less consolidated with DW values decreasing to ~10% and LOI 550 increasing to ~25% at the surface.

Figure 11 Stratigraphic data for OVER1



Spheroidal carbonaceous particle analysis

The SCP profile from OVER1 shows a SCP profile with clearly defined peak and rapid increase features (Table 7, Figure 12). The first presence of SCPs occurs at 35-36 cm while the peak concentration of almost 7000 gDM^{-1} occurs at 11-12 cm. It seems likely that this SCP profile does not represent the full industrial record of deposition since 1850, but rather is truncated at a point where SCP concentrations fall below the analytical detection limit.

If we ascribe the SCP concentration peak at 11-12 cm to 1978 ± 2 then this indicates a mean sediment accumulation rate over the last 30 years of 0.38 cm yr^{-1}. However, the rapid increase feature occurs at ~25 cm indicating that the sediment accumulation rate has not been consistent throughout. Instead this suggests a higher mean sediment accumulation rate between 1950 and 1978 of 0.48 cm yr^{-1}. Both rates indicate that the full SCP profile is truncated and if this earlier rate continues below 1950 then it would imply that the observed SCP record begins in the 1930s. Although it is not possible to provide any further dates below 1950 from the SCP record this rate would place 1850 between 70 and 75 cm depth. The best available chronology is summarised in Table 8.

Table 7 SCP concentrations for OVER1

Mean depth (cm)	SCP conc (gDM-1)	90% C.L. (gDM-1)
0.5	1444	708
1.5	2163	865
3.5	4580	1696
5.5	4724	1464
7.5	3818	1128
9.5	2518	933
11.5	6757	1770
13.5	5768	1413
15.5	5634	1531
17.5	4294	1331
19.5	4789	1355
21.5	5072	1572
23.5	3162	1095
25.5	1023	709
27.5	1170	662
29.5	381	373
31.5	358	351
33.5	1470	832
35.5	409	401
37.5	0	0
39.5	0	0
42.5	0	0
45.5	0	0
50.5	0	0
55.5	0	0
59.5	0	0
79.5	0	0

Figure 12 SCP profile for OVER1

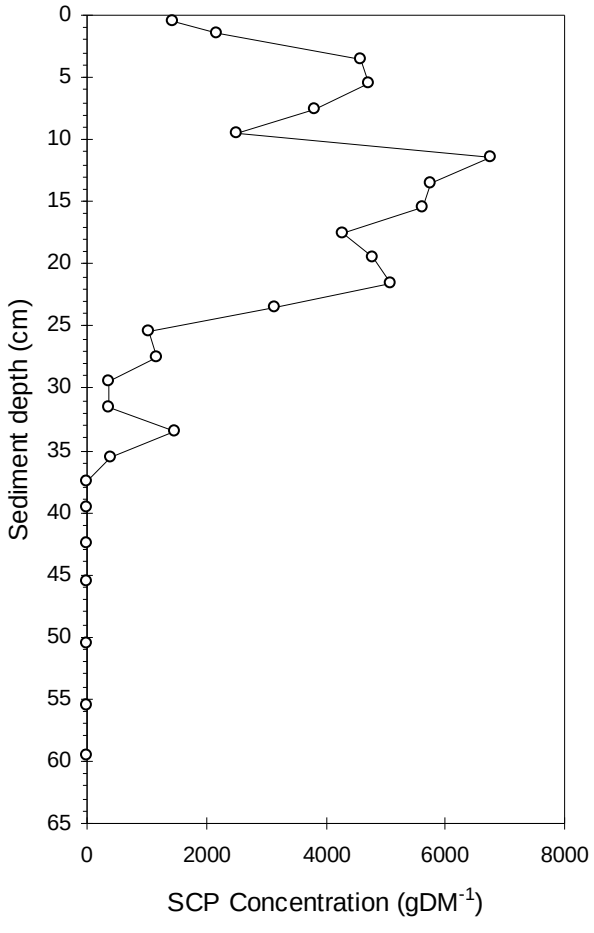


Table 8 The SCP derived chronology for OVER1

Sediment depth (cm)	Age (Years)	Date
0	0	2008
5	13 ± 2	1995 ± 2
10	26 ± 3	1982 ± 3
15	38 ± 5	1970 ± 5
20	48 ± 8	1960± 8
25	59 ± 10	1949± 10
30	69 ± 10	1939 ± 10
35	80 ± 15	1928 ± 15

SUNBIGGIN TARN

Core description

A piston core, 1.35 m in length, was collected from Sunbiggin Tarn on 19-Jan-08 in 2.3 m water depth, approximately 15 m from the shore on the southern side of the lake. At the time of coring, the water level was up by approximately 0.5 m due to recent heavy rainfall. Marginal vegetation was comprised of *Typha* and *Phragmites*.

The core had two distinct horizons (Figure 13). The upper 30 cm was mid-brown and the section below 30 cm was lighter greyish brown with a marl-like consistency and was rich in ostracod remains. *Chara* encrustations were abundant from 86 cm downwards

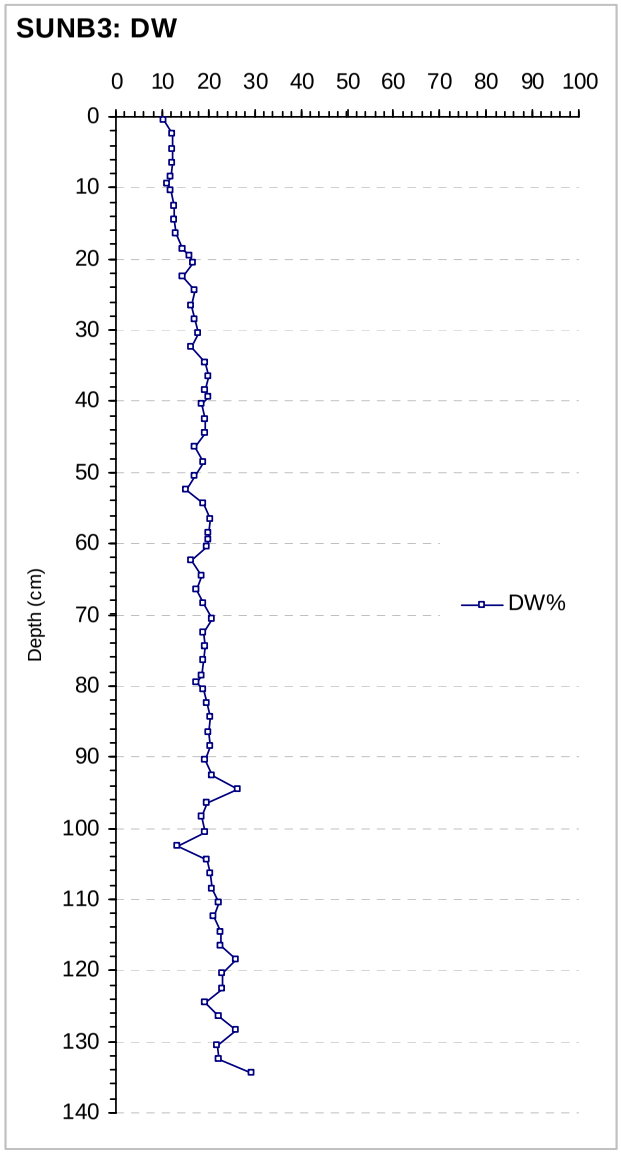
Figure 13 Sediment core stratigraphy of SUNB3

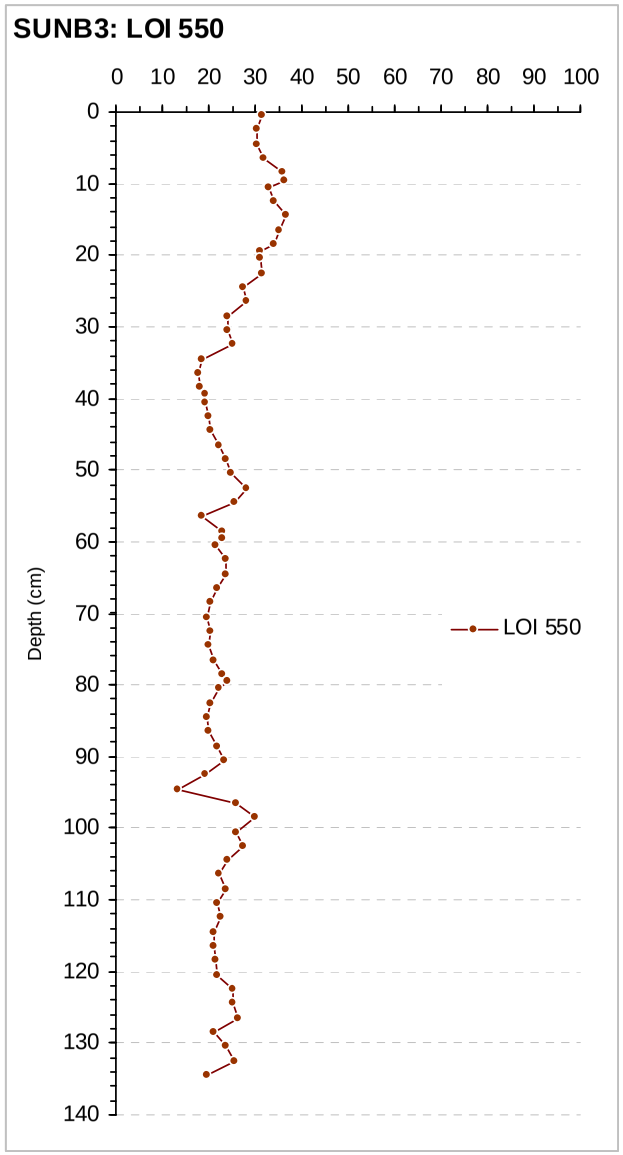
Depth (cm)	Sediment colour
0-30	Mid-brown
30-135	Light greyish brown

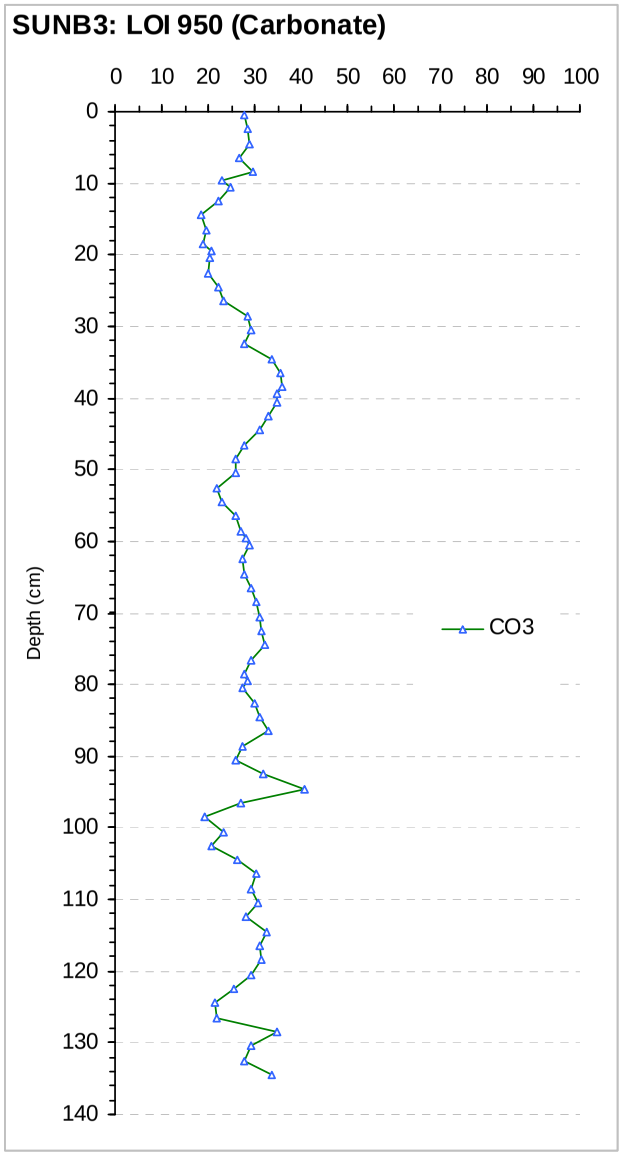
Stratigraphic analyses

Despite marked visible stratigraphy in SUNB3 (Figure 13), the profiles were relatively stable with only modest fluctuations and indicate that there have been no major changes in sediment type throughout the record (Figure 14). The DW values decrease gradually from ~30 to 10% reflecting the reduced consolidation of the younger sediments. The LOI 550 values fluctuate between ~20 and 35% with the highest organic content in the lowermost (below 95 cm) and uppermost (above 35 cm) sections and somewhat lower values in the mid section. Carbonate content is relatively high with values of ~20-30%, the lowest values occurring in the upper 30 cm.

Figure 14 Stratigraphic data for SUNB3







Spheroidal carbonaceous particle analysis

The SCP profile from SUNB3 shows a SCP profile with clearly defined peak of over 4300 gDM^{-1} at 34-35 cm (Table 9, Figure 15). If this peak is ascribed the date of 1978 ± 2 then this indicates a rapid mean sediment accumulation rate of 1.15 cm yr^{-1} over the last 30 years. Extrapolating this rate would place 1950, the time at which a rapid increase in SCP concentration is usually observed, at ~66 cm. The profile would suggest that this feature probably occurs slightly above this at ~60 cm indicating a mean sediment accumulation rate of ~1.0 cm yr^{-1} for the period 1950-1978 and a slight increase in accumulation rate in recent decades. This rapid accumulation rate would also suggest that if it continued below the analysed section then SCPs should still be present at the base of the core at 134-135 cm. However, if accumulation rates reduce further then the full SCP profile may be contained within this core. Further SCP analyses will be undertaken prior to the start of Phase 2 to confirm this. In the meantime, Table 10 summarises the chronology for the 0-80 cm section of this core.

Table 9 SCP concentrations for SUNB3

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	344	337
4.5	1202	589
9.5	0	0
14.5	975	676
19.5	758	525
24.5	790	447
30.5	2049	898
34.5	4359	1068
37.5	3811	1078
39.5	1844	738
42.5	1573	689
44.5	2568	890
47.5	934	916
49.5	958	664
52.5	1975	1117
54.5	1173	813
57.5	1656	1148
59.5	313	306
64.5	742	514
70.5	624	611
74.5	658	644
79.5	371	364

Figure 15 SCP profile for SUNB3

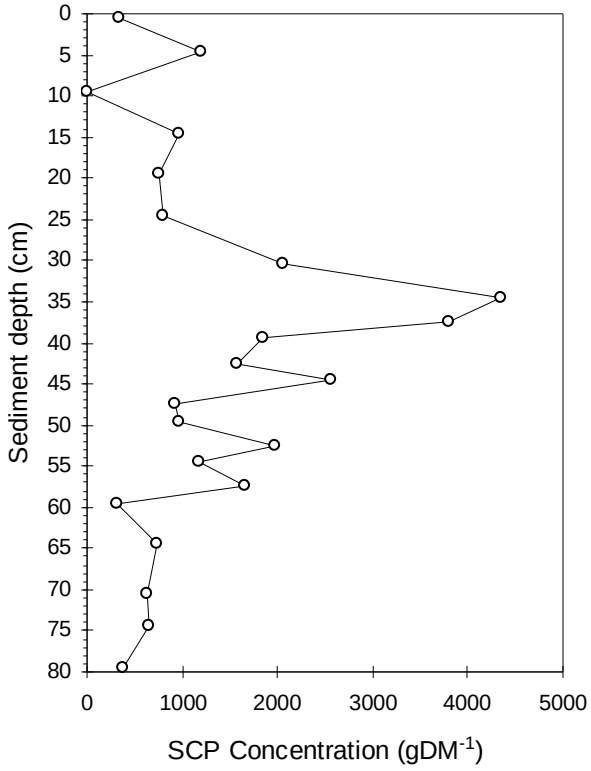


Table 10 The SCP derived chronology for SUNB3 (0-80 cm only)

Sediment depth (cm)	Age (Years)	Date
0	0	2008
10	9 ± 2	1999 ± 2
20	17 ± 2	1991 ± 2
30	26 ± 3	1982 ± 3
40	36 ± 5	1972± 5
50	46 ± 15	1962± 5
60	56 ± 8	1952 ± 8
70	66 ± 10	1942 ± 10
80	76 ± 15	1932 ± 15

SEMER WATER

Core description

A piston core, 0.91 m in length, was collected from Semer Water on 19-Jan-08 in 2.95 m water depth, approximately 20 m from the shore on the west side of the lake. At the time of coring, the water level was up by approximately 1.5 to 2 m due to recent heavy rainfall and local flooding and the water was turbid. Marginal vegetation was comprised of *Alder* carr.

There were three horizons in the core although there was a gradual transition between them rather than distinct layers (Figure 16). The upper 40 cm was mid-brown. This was followed by a greyish-brown section from 40-60 cm with higher clay content although the transition began at around 25 cm. The lower section from 60-91 cm was mid-brown again with lower clay content than the central section.

Figure 16 Sediment core stratigraphy of SEME3

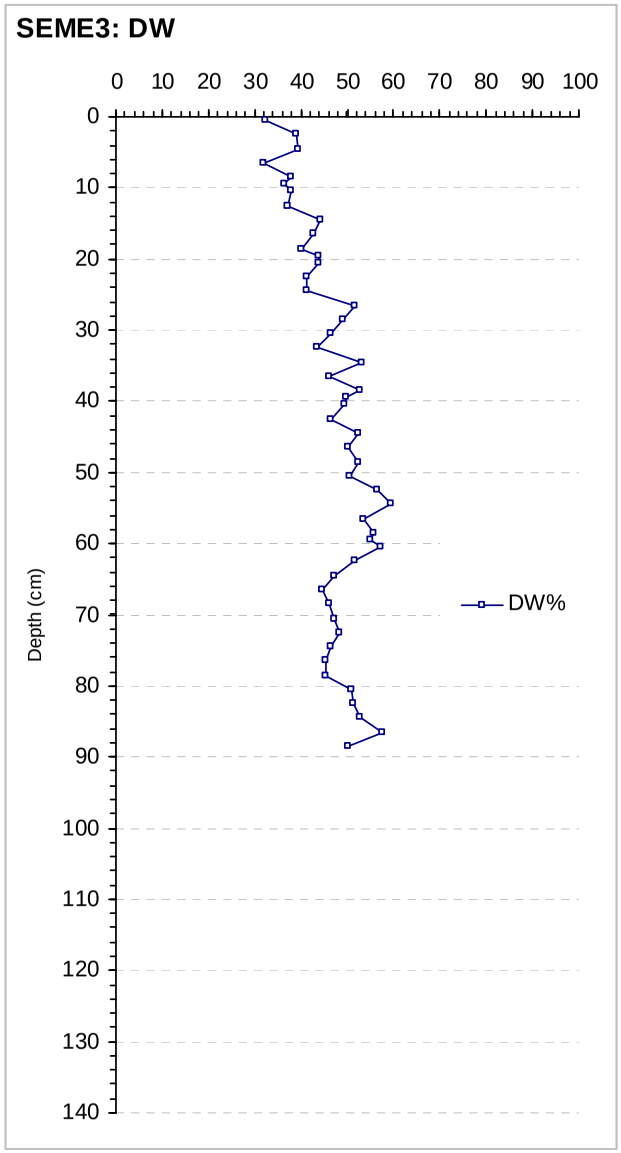
Depth (cm)	Sediment colour
0-40 (> 25)	Mid-brown (Transition to greyish brown begins)
40-60	Greyish brown
60-91	Mid-brown

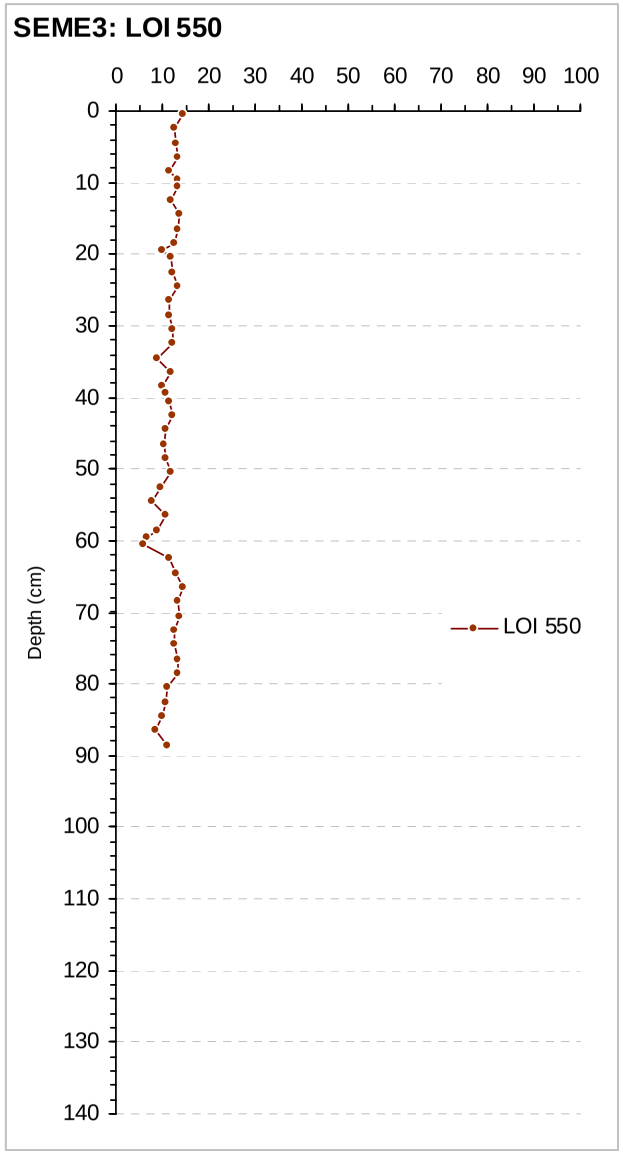
(NB Bottom of core missing from photograph)

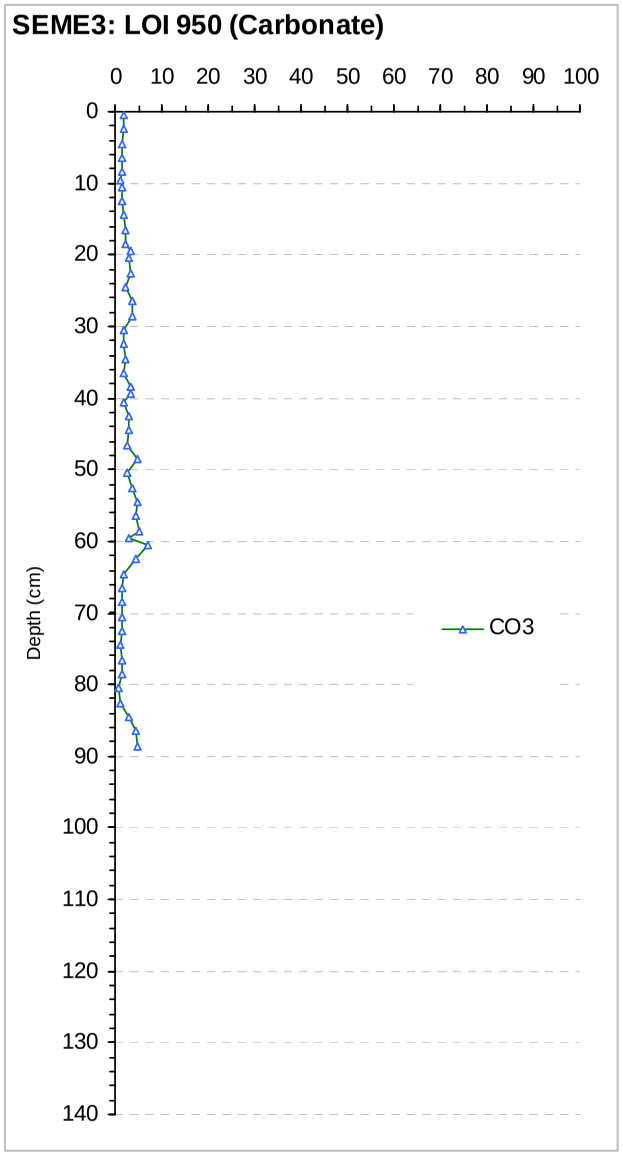
Stratigraphic analyses

The core, SEME3, was inorganic (LOI 550 10-15%) and low in carbonate (LOI 950 < 5%) throughout (Figure 17). There was little change in percentage organic matter although values were at their highest below ~60 cm. The section from ~65-80 cm had lower DW values (~45%) than the samples below or above it, owing to the higher organic content in this part of the core. The DW values declined steadily from a maximum of ~60% at 55 cm to ~30% at the surface, reflecting the lower density of the upper sediments.

Figure 17 Stratigraphic data for SEME3







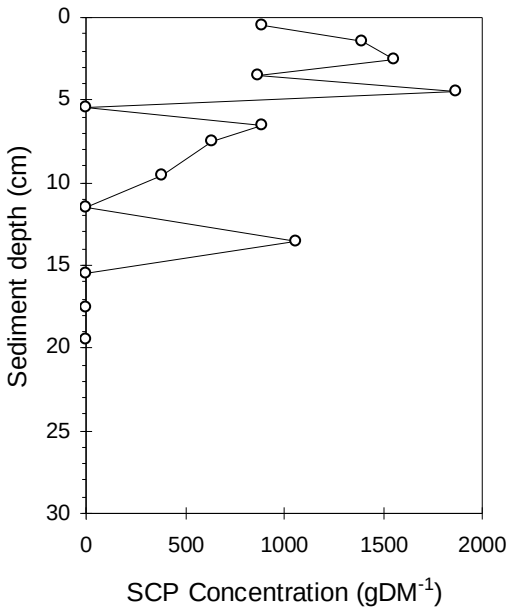
Spheroidal carbonaceous particle analysis

The SCP profile in SEME3 is highly irregular and fragmentary suggesting an incomplete record and possibly discontinuous sedimentation (Table 11, Figure 18). The first presence of SCPs occurs at 11-12 cm and the maximum concentration of almost 2000 gDM^{-1} occurs at 4-5 cm. If this represents the SCP peak, and it is difficult to be certain, then this would imply a mean sediment accumulation rate of ~0.15 cm yr^{-1} over the last 30 years. Extrapolating this would place 1950, and an expected rapid increase feature at 8-9 cm. While this is not inconceivable from the profile, the irregular nature of the observed SCP profile makes confidence in this extremely low. It is therefore not possible to provide a chronology for this core. From the presence of SCPs we can be sure that sediment above 13-14 cm is post-1850 and a best estimate would place the mid-late 1970s at 4-5 cm. However, no further dates can be ascribed and even this date should be treated with caution.

Table 11 SCP concentrations for SEME3

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	889	503
1.5	1398	969
2.5	1553	878
3.5	865	599
4.5	1870	693
5.5	0	0
6.5	892	504
7.5	641	628
9.5	382	374
11.5	0	0
13.5	1058	518
15.5	0	0
17.5	0	0
19.5	0	0
39.5	0	0
59.5	0	0
79.5	0	0

Figure 18 SCP profile for SEME3



MALHAM TARN

Core description

A piston core, 1.18 m in length, was collected from Malham Tarn on 20-Jan-08 in 2 m water depth, approximately 100 m from the shore on the north side of the lake. Marginal vegetation was comprised of mixed woodland.

There was one distinct change in the core and several more subtle features (Figure 19). The uppermost 5 cm was mid-brown. The section below this from 5-74 cm was a mid-grey grading to a darker grey by ~ 64 cm. The major change occurred at 74 cm when the sediment changed to a light-mid brown, marl-like material with molluscs and a stiffer consistency. From 92 cm to the core base the material was slightly lighter brown in colour and was less sticky with a drier texture than the marl section but still contained abundant molluscs.

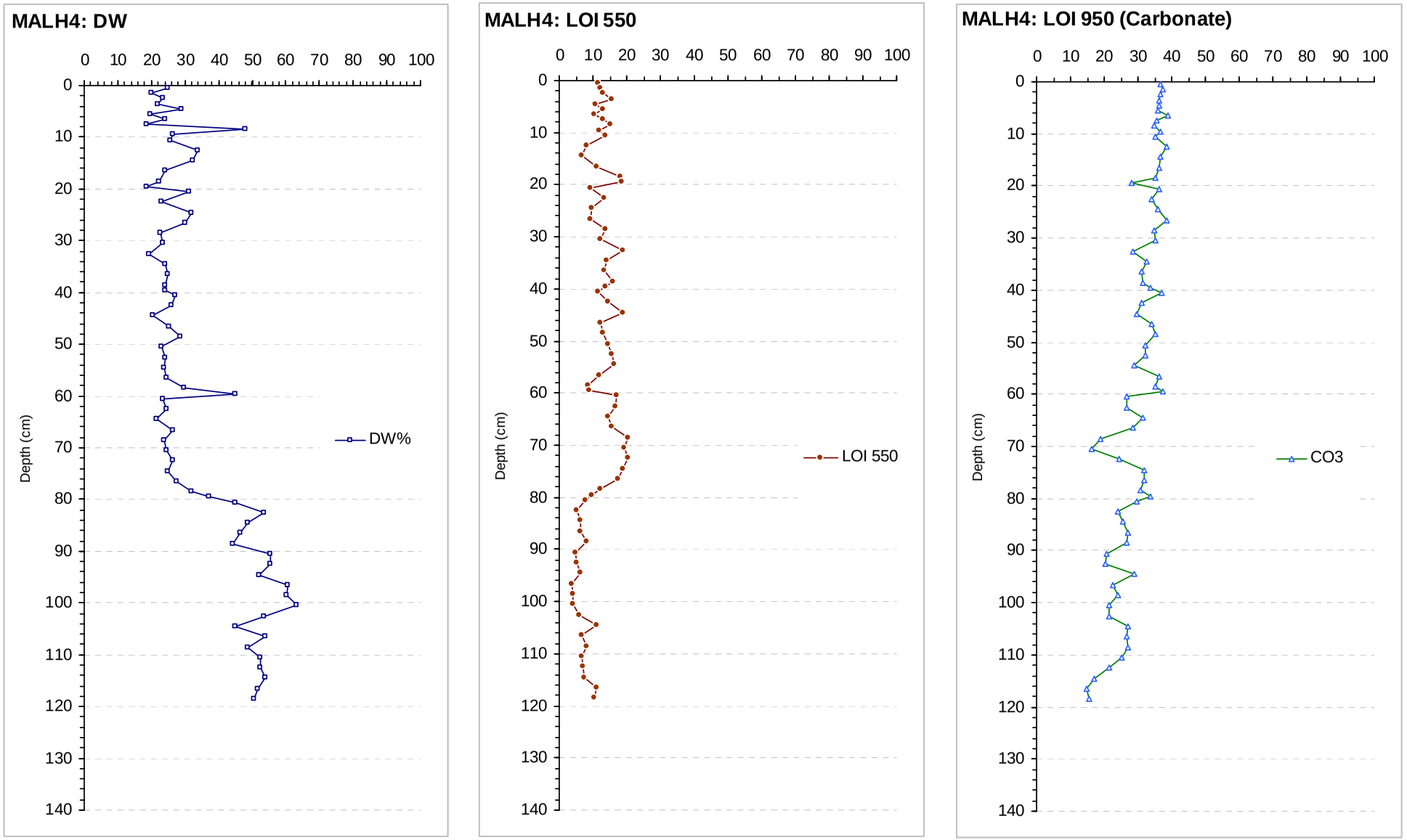
Figure 19 Sediment core stratigraphy of MALH4

Depth (cm)	Sediment colour
0-5	Mid-brown
5-67	Mid- grey (transition to dark grey)
67-74	Dark grey
74-92	Light-mid brown (molluscs present)
92-118	Light brown (molluscs present)

Stratigraphic analyses

The core, MALH4, was generally low in organic matter (LOI 550 <15%) and high in carbonate (LOI 950 >20%) throughout (Figure 20). However, the lowermost section below ~75 cm was markedly denser and less organic than the upper core with DW and LOI 550 values of ~60% and 5-10%, respectively. In contrast, DW values were typically only 20-30% and LOI 550 values were 10-15% in the upper section. The highest carbonate values of ~35% occurred in the upper core section above 60 cm.

Figure 20 Stratigraphic data for MALH4



Spheroidal carbonaceous particle analysis

The SCP profile from MALH4 shows clearly defined peak and rapid increase features (Table 12, Figure 21). The first presence of SCPs occurs at 49-50 cm while the peak concentration of over 6000 gDM^{-1} occurs at 9 -10 cm. A previous core from Malham Tarn (MALH2) shows a full SCP record and, in comparison, this MALH4 profile appears slightly truncated i.e. the low SCP concentration 'tail' at lower depths is curtailed.

The SCP concentration peak at 9-10 cm can be ascribed the date 1978 ± 2. The previous ^{210}Pb dated core (MALH2) also shows a well defined peak at this date. This date indicates a mean sediment accumulation rate of 0.31 cm yr^{-1} for the most recent 30 years. Extrapolating this rate would put 1950, and the expected rapid accumulation rate feature, at 18-19 cm, but in MALH4 this appears lower at 22-23 cm indicating a more rapid mean accumulation rate of ~ 0.41 cm yr^{-1} for the period 1950-1978. If extrapolated, both the recent and earlier accumulation rates would place 1850 below the observed first presence of SCPs. Therefore, either the accumulation rate is considerably lower at this time (~ 0.265 cm yr^{-1} for the period 1850-1950) or the profile has been truncated. It seems likely that it is the latter, given the shape of the rest of the profile. If this is the case, then extrapolation of the lower rate would put the start of the SCP record in the 1880s. If the more recent rate is used then the start of the SCP record would be in the 1860s and the profile would therefore be an almost complete industrial record. For information, all accumulation rates for MALH4 appear to be much higher than those for MALH2. A best available chronology for MALH4 is provided in Table 13. Dates prior to 1940 are uncertain and so are not included.

Table 12 SCP concentrations for MALH4

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	3968	1123
2.5	1982	869
4.5	1321	915
6.5	4193	1186
7.5	4606	1095
9.5	6015	1430
11.5	5331	1847
12.5	5159	1911
14.5	5161	1460
16.5	4811	1491
18.5	4252	1318
19.5	5504	1626
22.5	1663	815
24.5	2780	1362
27.5	957	663
30.5	1062	736
32.5	1452	1006
34.5	1162	569
39.5	801	555
44.5	0	0
49.5	613	601
54.5	0	0
59.5	0	0
79.5	0	0

Figure 21 SCP profile for MALH4

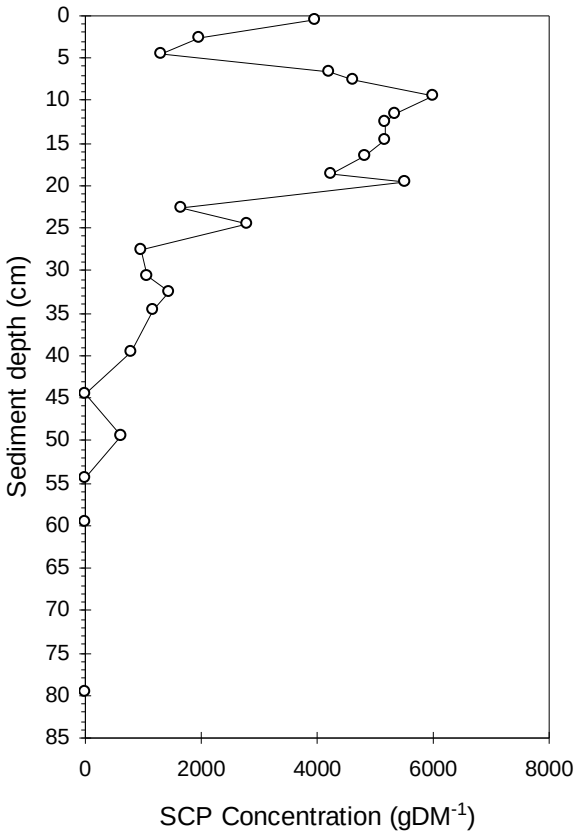


Table 13 The SCP derived chronology for MALH4

Sediment depth (cm)	Age (Years)	Date
0	0	2008
5	16 ± 2	1992 ± 2
10	32 ± 2	1976 ± 2
15	44 ± 3	1964 ± 3
20	56 ± 5	1952 ± 5
25	68 ± 8	1940 ± 8

HORNSEA MERE

Core description

A piston core, 1.32 m in length, was collected from Hornsea Mere on 21-Jan-08 in 1.75 m water depth, approximately 20 m from the shore on the northern side of the lake. At the time of coring, the water level was up by approximately 0.5 m due to recent heavy rainfall and the water was very turbid. Marginal vegetation was comprised principally of *Phragmites*.

The core was homogeneous and mid-brown in colour throughout the upper 90 cm with little visible colour change except for a slight lightening to a greyish brown, slightly denser material below 90 cm (Figure 22). Photographs were taken but were of poor quality owing to the adverse weather conditions and are therefore not shown.

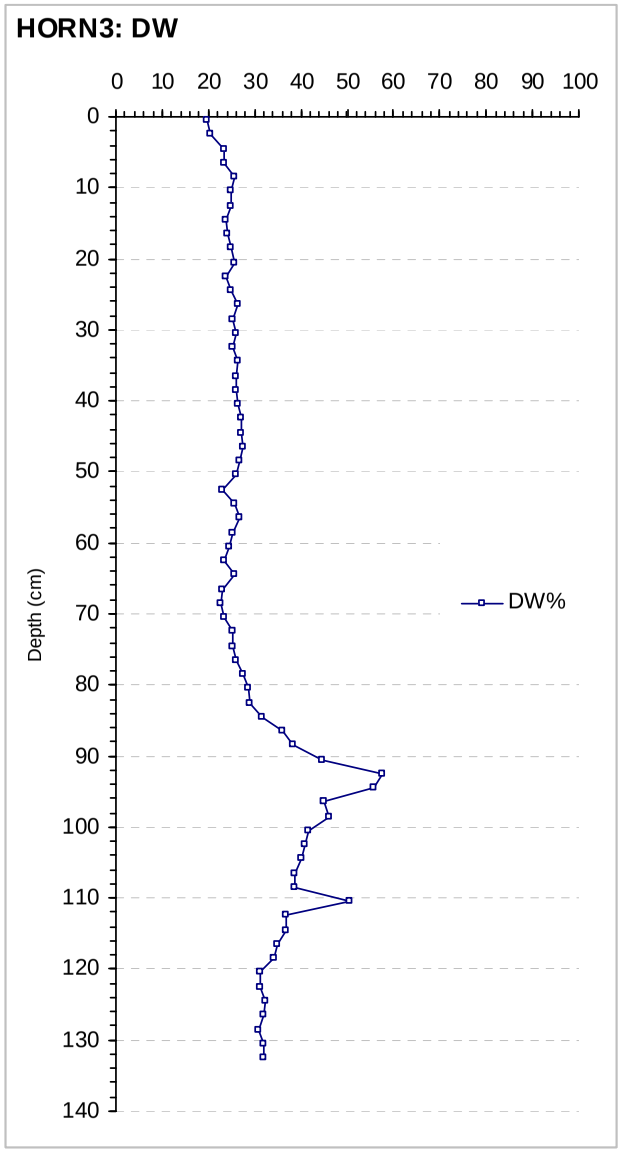
Figure 22 Sediment core stratigraphy of HORN3

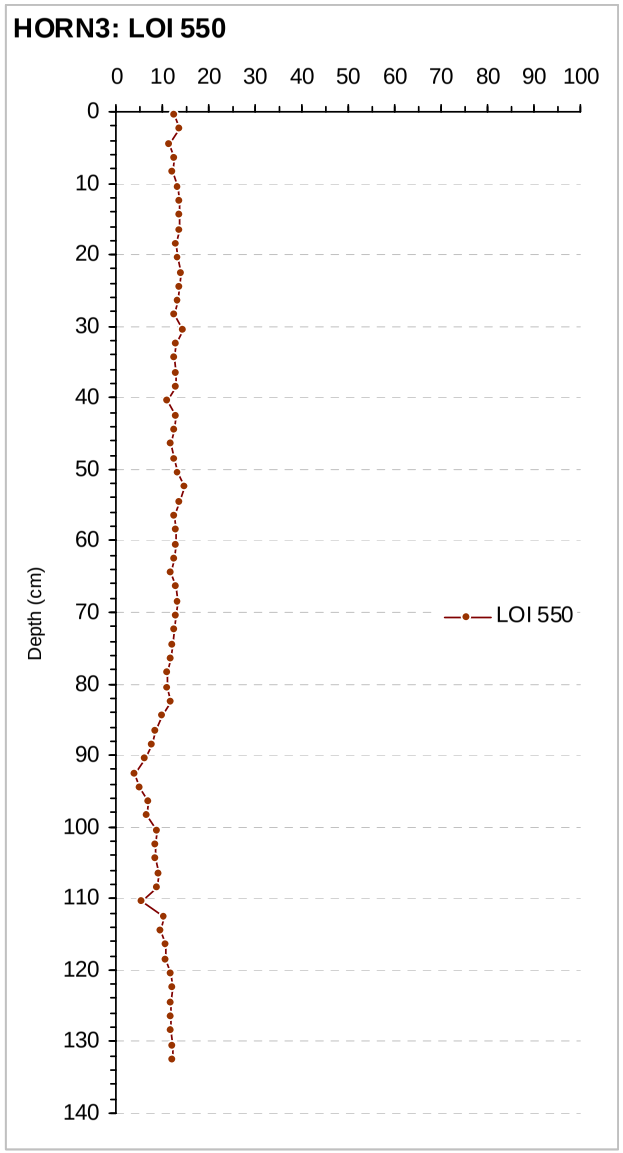
	Depth (cm)	**Sediment colour**
No photo	0-90	Mid-brown
	90-132	Greyish brown

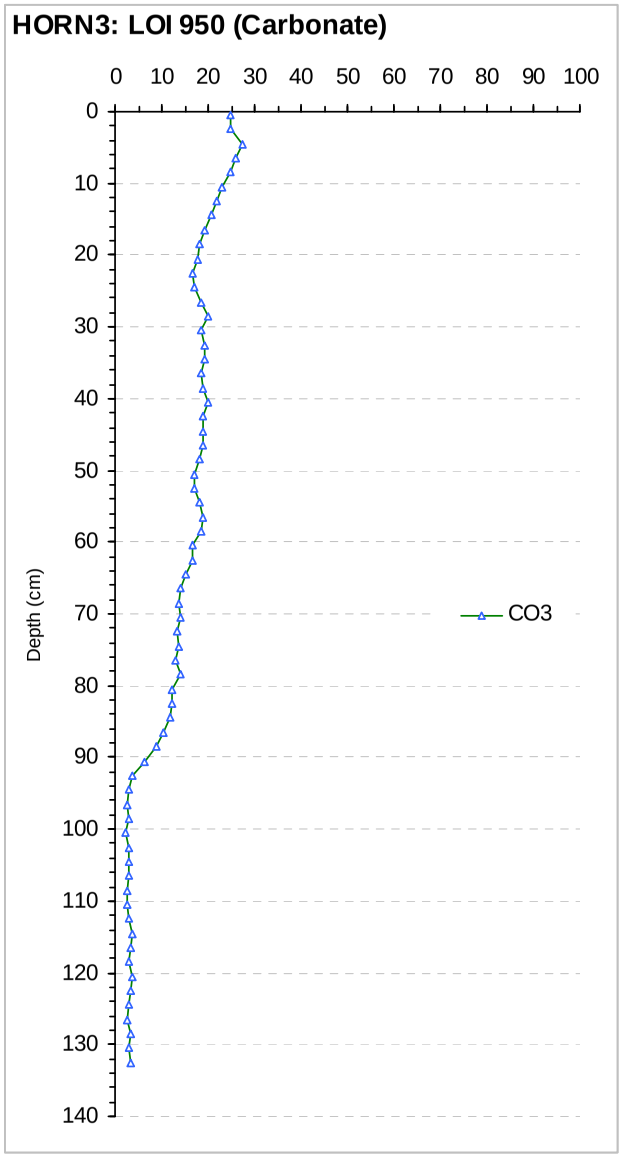
Stratigraphic analyses

The core, HORN3, was generally low in organic matter with relatively stable LOI 550 values of ~10-15% throughout (Figure 23). However, the lowermost section below ~90 cm was markedly denser than the upper core with DW values in excess of 30% (maximum 58%) compared with values of 20-25% throughout the upper core. Below this same depth, the carbonate content was stable and markedly lower than that above 90 cm with values of only 2-3%. The carbonate content gradually increased from the 90 cm level upwards to values of ~25% at the surface.

Figure 23 Stratigraphic data for HORN3







Spheroidal carbonaceous particle analysis

The SCP profile from HORN3 shows a SCP profile with clearly defined peak of over 4400 gDM^{-1} at 10-11 cm although the rapid increase feature expected in 1950 is less obvious (Table 14, Figure 24). If the SCP peak is ascribed to 1978 ± 2 then this indicates a mean sediment accumulation rate of 0.35 cm yr^{-1} over the last 30 years. Extrapolating this rate would place 1950 at around 20 cm which, from the profile, seems quite possible. This would suggest that the mean sediment accumulation rate in HORN3 has remained reasonably stable over the last 50-60 years. Further extrapolation would place 1850 at ~55 cm. Although this lies below a sample in which no SCPs were found, additional samples will be analysed prior to Phase 2 to confirm whether this is the case. If no further SCPs are found, then this profile is probably truncated at around the turn of the 20th century. In the meantime, Table 15 summarises the current best estimate of the chronology for the 0-40 cm section of this core.

Table 14 SCP concentrations for HORN3

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	294	581
2.5	2005	2699
4.5	2497	3176
6.5	2923	3935
8.5	2179	3134
9.5	2118	3046
10.5	4428	5632
12.5	3891	5239
14.5	3779	5631
16.5	1954	2677
18.5	2719	3726
19.5	1285	1915
22.5	1496	2342
24.5	1133	1918
27.5	938	1469
30.5	688	1165
32.5	674	1141
34.5	1083	1695
37.5	325	644
39.5	0	0
59.5	0	0
79.5	0	0

Figure 24 SCP profile for HORN3

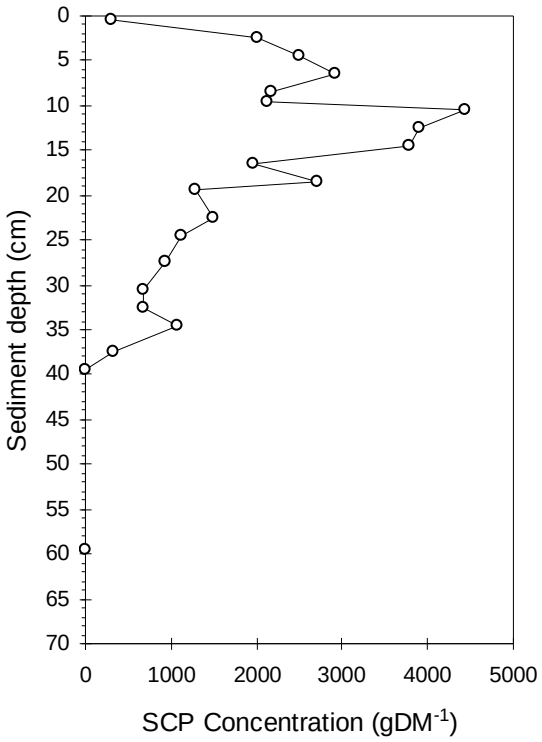


Table 15 The SCP derived chronology for HORN3 (0-40 cm only)

Sediment depth (cm)	Age (Years)	Date
0	0	2008
5	14 ± 2	1994 ± 2
10	28 ± 2	1980 ± 2
15	43 ± 3	1965 ± 3
20	57 ± 5	1951 ± 5
25	71 ± 10	1937 ± 10
30	86 ± 15	1922 ± 15
35	100 ± 20	1908 ± 20
40	114 ±20	1894 ± 20

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