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Palaeoecological assessment of freshwaters in SACs and ASSIs in Northern Ireland

Final report to the Environment and Heritage Service

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Executive Summary

This is the final report to the Environment and Heritage Service (EHS) in Northern Ireland on the 'Palaeoecological investigation of the past biological structure and function in Freshwaters in SACs and ASSIs.

Sediment cores were taken from semi-littoral or open water areas of each of the eleven loughs, two in the summer of 2006 and nine in June 2007. The cores were extruded in the field, stratigraphic changes were noted and the percentage dry weight and organic matter content of each core were subsequently determined in the laboratory. Sediment samples from each of the open water cores were analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs and ^{241}Am by direct gamma assay in order to provide radiometric dates. Reasonable chronologies were established for eight of the cores and indicated that the records covered a period of at least 100-150 years, although at three sites, there were very low concentrations of ^{210}Pb and ^{137}Cs were detected and, therefore, a reliable chronology could not be produced for these site. These were Killymackan, Upper Lough Erne – Trannish and Knockballymore C.

Different permutations of analyses were undertaken at each site according to the suitability of each analysis at each site. For example at Lough Atona, in the Cuilcagh Mountains SAC and Glenbower Lough on Slieve Beagh only diatom analysis was carried out as it was the single most appropriate analysis at these low alkalinity low productivity upland sites. At the more productive, higher alkalinity sites where submerged plants were more likely to be abundant plant macrofossil analysis was carried in order to track changes in the dominant component of the past submerged flora of the sites. Cladoceran analysis was also carried out as it elucidates on shifts in the ecological function in lakes providing insights into causes of changes in the submerged flora of each lake. The key findings for each Lough are as follows:

Loughnatrosk
To summarise Loughnatrosk appears to have undergone a fairly profound shift in macrophyte flora over the time period represented by the sediment core, about 500 years. It initially had a more meso-oligotrophic flora containing *L. dortmanna*, *Chara* and *Nitella* species, abundant *Ranunculus* subgenus *Batrachium* species and a diverse *Potamogeton* flora including broad and fine leaved species. After 1700, productivity may have risen, suggested by the increases in %LOI and planktonic cladocerans, which may have resulted in the loss of the more oligotrophic macrophyte species. The system appears to have then been relatively stable until around the 1950 where sediment accumulation rates rose and there was shift towards more fine-leaved *Potamogeton* species, although the oospore numbers for both *Chara* and *Nitella* suggest there are still healthy populations at the site.

Loughgarve
The data from Loughgarve was more difficult to interpret but suggests there has been an overall decline in the ecological quality of the site, as reflected by submerged macrophyte flora. *Lobelia dortmanna* was formerly present as the site and *Nitella* species were also formerly more abundant. The progressive shallowing of the site and wind stress and mixing of sediments may have had a detrimental effect on submerged plant performance at Loughgarve. Notwithstanding problems isolating the causes it is clear there has been some change in the flora over time period represented by the sediment core.

Mill Lough
Given the quality and importance of Mill Lough in conservation terms it is unfortunate that the plant remains in the core were not more numerous. The different biological groups did, however, provide some insights into changes in the ecological structure and function of the site over the past, at least, 800 years. The macrofossil profile suggests an increase in the abundance of *Chara* spp in the upper zone of the core, with perhaps a decline in the last 20 years. It would not be possible to make this assertion of contemporary decline based on the macrofossil record alone, however both the diatom

and cladoceran profiles indicate some eutrophication induced change in the last 20 years with increases in the abundance of planktonic taxa. The cladoceran data indicated that eutrophication induced promotion of planktonic primary production was initiated at around 55 cm with the increase in planktonic taxa *B. longirostris* and some *D. hyalina* which are symptomatic of the early stages of eutrophication. Despite these signs of eutrophication induced changes to the system the cladoceran assemblage does not indicate a decline in macrophyte abundance as the number of epiphytic cladoceran species , e.g. *G. testudinaria, E. lamellatus* are numerous in the top sample.

Killymackan

The palaeoecological data for Killymackan Lough suggest that there have been profound changes in the ecology of the site. Initially the macrophyte flora was dominated by *Nitella* spp. with benthic species of cladocerans and diatoms reflecting the overwhelming dominance of benthic primary production. There followed a relatively gradual change where pelagic taxa of both diatoms and cladocerans have become more common indicating an increased proportion of pelagic primary production as a result of eutrophication. This has occurred in concert with a change in macrophyte flora to dominance by fine leaved *Potamogeton*, with *Callitriche* and *Chara* also present. These changes reflect a change in the controls on productivity of the system of the ecosystem. Formerly bottom up forces, or resources, in this case nutrients controlled the algal productivity, particularly the pelagic production, currently it appears that top-down pressures, i.e. the grazing of zooplankton, controls the phytoplankton crop.

Upper Lough Erne - Trannish

This core was analysed at lower resolution but indicated that there has been a shift from the dominance of benthic to pelagic productivity towards the top of the core. The macrofossil data suggest a decline in diversity with a shift to fine leaved *Potamogeton* species and *N. alba* at the top of sequence. Due to the radiometric dating producing unreliable results it is impossible to ascribe dates to the core. Of interest, however, are the abundant remains of *Najas flexilis*, a species absent from Northern Ireland today but apparently common in Upper Lough Erne in the past.

Kilroosky

The combined physical, in particular the lithostratigraphy, and the biological data demonstrate the site has undergone substantial change over the time period represented by the core. Based on the extrapolation of accumulation rates in the lower section of the core, it can be speculated that the base of the core at around 120 cm correspond to about 800 AD and that the major change in macrofossil stratigraphy and %LOI, if taken at 70 cm would be placed around 1300 AD. Prior to this the sediments were very high in organic matter with levels (>70%) that suggest peat. There was a gradual change in the system to a marl system which is rich in carbonate and has an abundant and diverse *Chara* flora. Since that time Kilroosky has been a base rich lough dominated by *Chara*, with a rich mollusc fauna. The cladoceran and the mollusc data suggest that in the last 50 years there has been an increase in the plankton of the site, as the number of planktonic species increased and mollusc density has fallen, perhaps as a result of nutrient enrichment. The cladoceran data, however, also suggest that there has been an increase in macrophyte abundance in this time period with an increase in the proportion of plant associated cladocerans. The shift in the benthic fauna, from molluscs to cladocerans, could result from nutrient enrichment but fish could also drive such a change.

Knockballymore C

The poverty of plant remains make it difficult to comment on changes in the wider submerged plant community. Despite the low numbers of remains there is a striking similarity with the patterns at Kilroosky, in that there is a general shift from the dominance from water-lily to *Chara* remains. The ^{210}Pb data suggests that the top 10 cm were disturbed or mixed to some extent, this may explain the presence of *Chara* in the surface sediments when no charophytes were recorded in Knockballymore C Lough in the most recent contemporary survey or a previous survey carried out on 02/08/1988 (NILS). The cladoceran data strongly indicate that the lake has declined in ecological quality. There was a shift away from a diverse assemblage containing numerous plant associated species characteristic of lakes with a species rich macrophyte community to an assemblage in the top two samples, containing fewer species, including *B. longirostris*, *A. affinis* and *A. quadrangularis* which are characteristic of increased turbidity and fewer submerged macrophyte species.

Meenatully Lough

At Meenatully the cladoceran and diatom data suggest that the lough has always had a significant planktonic production with numerous remains of planktonic species throughout the core *D. hyalina* agg. and *Cyclotella radiosa* in the cladoceran and diatom record respectively. In contrast to more shallow lakes this appears to have had little adverse impact on the macrophyte flora as is evinced by the rich macrofossil assemblage for the lower section of the core. The change in assemblages between zones 1 and 2 may be the result of slight enrichment showing an increase in productivity as with a slight shift along the gradient from oligotrophic to mesotrophic as species richness may have increased and the abundance of the more oligotrophic species *I. lacustris* and *L. dortmanna* appears to have declined. The final change which has occurred in the last 50 years saw the loss of *Chara* and the probable loss of *Nitella,* there was a concomitant shift in the cladoceran assemblage to dominance by planktonic taxa such as *B. longirostris* and *Ceriodaphnia* spp. and in the benthic species *C. piger* increased in abundance. The shift in the diatom data, i.e. the decrease in *Cyclotella* and increase in *Fragilariforma virescens* var. *exigua* may suggest a decrease in pH/ calcium content, which had a very low value in June 2006 (pH 4.6). This accords well with the other data, such as the shift away from Charophytes and perhaps the loss of *D. hyalina* agg. Thus, whilst it does not appear the site is acidified, in terms of very low pH, it may well have undergone a significant decline in alkalinity most likely resulting from acid deposition.

Lough Rushen

This was a difficult core to interpret as there are few remains but those that do occur, in particular for the macrofossils varied greatly in number. There was also a large area of the core, between 95 and 55 cm with very few macrofossil remains, where diatoms were dissolved and cladocerans remains were sparse. The shift in the upper zone above 10 cm , corresponding to the last 50 to 100 years, suggest a change from an oligotrophic to a mesotrophic flora, with *I. lacustris* and *L. dortmanna* remains lost from the sediment record. The shift in the cladoceran assemblage from *D. hyalina* to *B. coregoni* is more difficult to interpret and may result from changes in the food-web of the site, as this shift is associated with an increase in zooplanktivorous fish density. Whether the effects of reduced grazing pressure with the removal of the larger Daphnids has cascaded down the trophic levels resulting in increased algal crop is difficult to ascertain. The contemporary measurements of chlorophyll-*a* were perhaps a little high over the summer period in 2006, suggesting the site may be at risk.

Glenbower Lough

The diatom flora of Glenbower Lough were characterised by robust tolerant flora capable of withstanding the lower light conditions of brown-water sites with relatively low pH. The changes may suggest there has been a slight reduction in pH over the time period represented by the core. There does not, however, appear to have been a great deal of change at this site.

Lough Atona

Diatom preservation was very good throughout core. The time period represented by the core is very short representing only the last 30 years in 24 cm. This is almost certainly the result of sediment focussing at the coring site rather than very high production within the lough. The changes in the diatom assemblage suggest that conditions at the base of the core were perhaps less acidic or that there has been a decline in alkalinity up-core. This would indicate that there has been a decline in productivity over the last 30 years.

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Photo – *Nymphaea alba* flower

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Background

The last 150-200 years have witnessed substantial changes to the composition and abundance of submerged plant communities in European lakes. In soft waters systems, usually associated with upland areas, acid deposition has often led to the loss of sensitive species and thus a reduction in species diversity. In lowland areas eutrophication has resulted in substantial reductions in species richness, with losses of many characteristic species (Jupp & Spence 1977; Sand-Jensen 1997; Sand-Jensen *et al*. 2000) and ultimately the total disappearance of submerged vegetation and a shift to phytoplankton-dominance and 'turbid' water (Mason & Bryant 1975; Moss 2001).

A key mechanism in conserving and managing our standing waters today is not only brought about through contemporary monitoring, but also by gaining an understanding of how and why water quality and aquatic communities have changed through time. Long-term biological and chemical records spanning more than a century are very rare (Jackson 1978; Sayer *et al.* 1999), and as a consequence palaeolimnology often affords the only available means of determining the composition and architecture of underwater vegetation in the past (Birks 2001).

The use of palaeoecological techniques for establishing reference conditions for lakes has developed apace over the last decade, with many examples of their application to aquatic management and conservation (e.g. Battarbee 1999). Numerous previous studies have explored the causes, rates and magnitude of water quality change resulting from pressures such as eutrophication (e.g. Bennion *et al.* 2004) and acidification (e.g. Jones *et al*. 1993) by looking at the changes in the fossil diatom assemblages found in lake sediments. More recently research at ECRC/ENSIS has focussed on developing palaeolimnological techniques capable of providing information on former macrophyte communities by the analysis of aquatic plant remains (fruits, seeds, spores and vegetative fragments). This technique, known as plant macrofossil analysis, can provide a means with which to determine the past composition, structure and dynamics of in-lake macrophyte communities (Davidson *et al.* 2005; Zhao *et al.* 2006). The analysis of cladoceran remains can be employed, both in conjunction with other methods and on their own, to assess changes in lake ecosystem function which may have caused alterations in the macrophytes assemblage, e.g. by providing evidence of shifts in the fish population.

Methods

Coring and lithostratigraphic analysis

11 sediment cores were extracted using either a Glew corer (Glew 1991) or and adapted Livingstone type fat piston corer (Livingstone 1955) in the summer of 2006 or 2007 (Figure 1). The exact location of each core was recorded using a hand-held GPS. Summary details of the cores are given in Table 1.

Selection of the optimal sampling location was subject to conflicting pressures as dating techniques have been developed on cores taken from the deepest point of a lake, where accumulation rate is assumed to be greatest and bio-turbation minimal, whereas macrofossil analysis is best carried out on cores located more in the littoral zone (Davidson *et al*. 2005). Site selection was based on a compromise between these two opposing influences. The cores were extruded in the field at 1 cm intervals and any visible stratigraphic changes were noted. The percentage dry weight (%DW) which gives a measure of the water content of the sediment, and percentage loss on ignition (%LOI) which gives a measure of the organic matter content, were determined in the laboratory on alternate samples from each core by standard techniques (Dean 1974). The carbonate content was calculated by returning the crucible to the furnace for two hours at 925 ^{o}C and then reweighing.

Dating

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

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

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

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

Diatom analysis

Diatom slides were prepared from selected sub-samples of the seven cores (see Table 1 for details), using standard techniques (Battarbee 1986). Ten slides from each core were analysed to identify down core shifts in diatom assemblages using a Leitz research microscope with a 100x oil immersion objective and phase contrast. Principal floras used in identification were Krammer & Lange-Bertalot (1986-1991). A minimum of 300 valves were identified in each sample. All diatom data are expressed as percentage relative abundance.

Indirect ordination techniques (Principal components analysis- PCA) were used to analyse the variance within the diatom assemblages for each of the cores using CANOCO version 4.5 (ter Braak 2002). The technique in effect summarises the main floristic changes in the data and helps identify zones of change within the data sets. The sample scores for PCA axis 1 are illustrated in the summary diatom diagrams.

Macrofossil analysis

In the absence of reliable historical information on past aquatic macrophyte communities, analysis of sedimentary macro-remains of plants (the seeds, fruits and remains of stems, leaves and rhizomes) may provide a technique for determining changes in the aquatic flora of a site (Birks

1980). Recent work has indicated that plant macrofossils provide a reliable means for tracking shifts in the dominant components of the submerged aquatic flora in shallow lakes (Davidson *et al*. 2005).

For the macrofossil analysis 10 levels from TROS1, LGAR1, LMIL1, KILL1, KILR1, KNOC1, MEEN1, and RUSH1 were analysed and 5 samples from ULET1 were examined. A measured volume of sediment (*c.* 30 cm^3, the exact volume was assessed using water displacement) was analysed for each level. Samples were sieved at 350 and 125 microns and the residues from each were transferred using distilled water to plastic vials for storage. The entire residue from the 350 micron sieve was examined under a stereomicroscope at magnifications of X10-40 and plant and animal macrofossils were identified and enumerated. A quantitative sub-sample, approximately one fifth of the sample, from the 125 micron sieve sample was analysed for smaller remains such as leaf spines. All material was identified by comparison to reference material.

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

Larger animal remains are generally enumerated as part of macrofossil analysis in the same way as plant remains. The abundance of the ephippia of the different *Daphnia* species were determined this way. At most sites remains were sparse and thus interpretation difficult. At Kilroosky animal remains, in particular molluscs, were plentiful and thus these results are presented.

Cladoceran analysis

Cladocera are microscopic crustaceans (zooplankton) and are represented in lake sediments by a variety of body parts. The composition of both the contemporary community and their sedimentary remains have been shown to reflect changes in habitat structure (i.e. macrophytes) and zooplanktivorous fish density in shallow lakes (Jeppesen *et al*. 2001; Davidson *et al*. 2007). 10 samples were analysed in TROS1, LGAR1, LMIL1, KILL1, KILR1, KNOC1, MEEN1, and RUSH1 were analysed and 5 samples from ULET1 were examined. Sediment samples from each of the cores were prepared using an adaptation of the standard sub-fossil cladocera preparation technique (Korhola & Rautio 2000). This adapted method is based on that currently employed by colleagues working on Danish lakes (Jeppesen *et al*. 1996). For each sample at least 5 cm^3 of sediment was heated in a deflocculating agent (10% potassium hydroxide, KOH) and sieved at 150 µm and 50 µm. The retents of the two sieves were then washed into separate pots and safranin stain was added. Chitinous remains of cladocera from a sub-sample were enumerated using a compound microscope and identified with reference to Flössner (1972), Frey (1958; 1959) and Alonso (1996). Counting of individuals followed the minimum number method: head shields, carapaces and post abdominal claws were tabulated separately, the count for each species being the number of the most numerous remain. These data are presented as relative abundance of chitinous remains.

Ephippial remains were separated and counted along with macrofossil remains using a binocular microscope, thus the counts are based on the analysis of at least 30 cm^3 of sediment and are expressed as numbers per 100 cm^3. The sedimentary cladoceran record, based in chitinous remains alone, is incomplete, with a greater diversity of littoral chydorids being preserved compared to planktonic cladocerans (Hoffman 1987; Hann *et al*. 1989). Planktonic cladocera, particularly large bodied species, are most susceptible to fish predation (Brooks & Dodson 1965). Furthermore, the larger species, such as *Daphnia* spp. and *Ceriodaphnia* spp. are keystone species for shallow lake ecosystem function and records of changes in their abundance are crucial in determining past ecosystem function. Recent developments in cladoceran based palaeolimnology have incorporated ephippia data (Jeppesen *et al*. 2001) and demonstrated that the sedimentary assemblage is a good reflection of the population that formed it (Davidson *et al*. 2007). Thus, in order to determine the past effects of fish and record shifts in ecosystem function it is vital that ephippia are enumerated. *Daphnia* ephippia were identified to the highest taxonomic resolution possible, with remains ascribed to one of three guilds: *Daphnia hyalina* agg. consists of a number of smaller bodied species, such as *Daphnia longispina, D. hyalina, D. cucullata* and *D. galeata*, whereas *D. pulex* and *D. magna* can be identified to species. *Ceriodaphnia* spp. is the highest taxonomic resolution for the various *Ceriodaphnia* species.

Results

Figure 1 shows the location of the 11 sites that from part of this study, details of the sites and cores are given in Table 1.

Figure 1 Distribution of sites investigated in Northern Ireland.

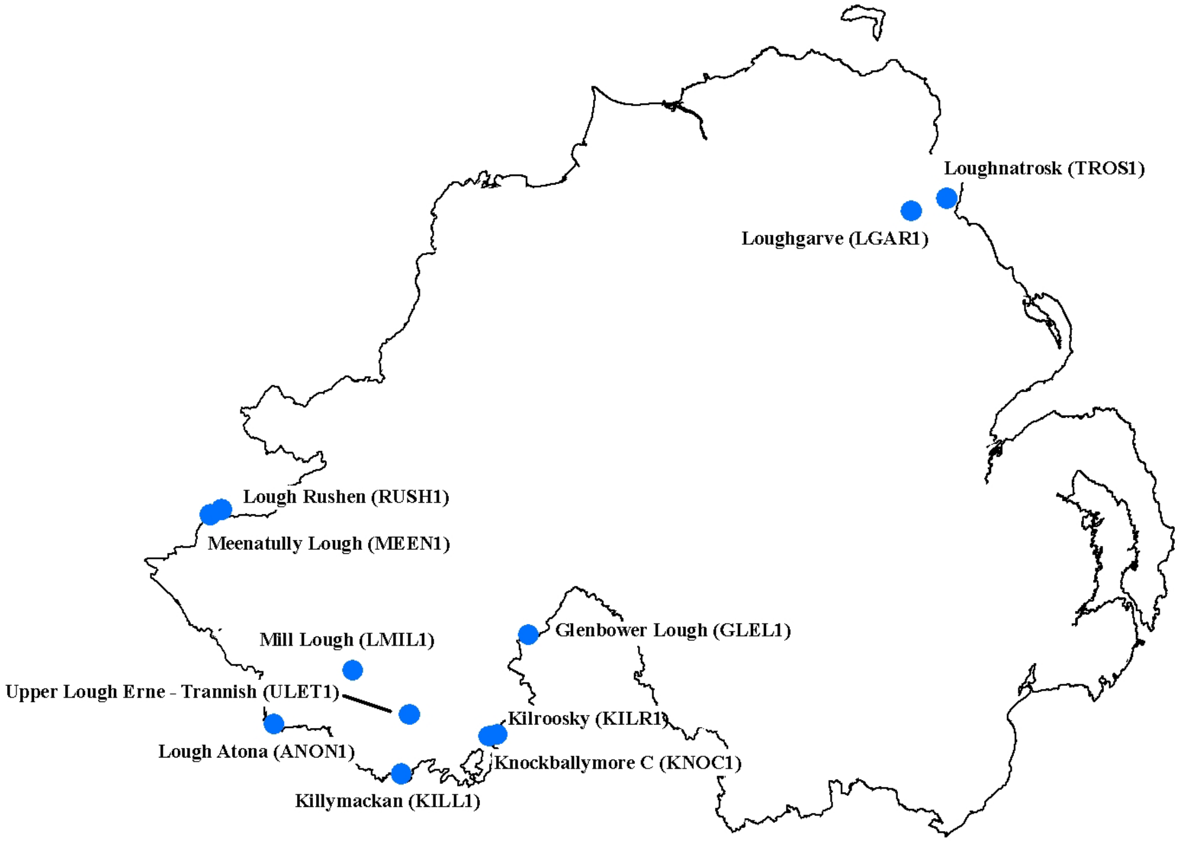


Table 1 Details of site, cores and analyses completed (M - Macrofossil; C – Cladoceran; D – Diatom)

Site	Area	NGR	Core code	Date	Core site water depth (cm)	Core location	Core length (cm)	Core type	Analysis
Loughnatrosk	Garron Plateau	D272199	TROS1	19/6/07	120	D27256 19870	92	Fat Livingstone	M, C & D
Loughgarve	Garron Plateau	D211177	LGAR1	7/6/06	70	D21070 17672	85	Fat Livingstone	M, C & D
Mill Lough	Upper Lough Erne	H246385	LMIL1	24/6/07	260	H24534 38218	149	Fat Livingstone	M, C & D
Killymackan	Upper Lough Erne	H330207	KILL1	24/6/07	120	H33059 20525	147	Fat Livingstone	M, C & D
Upper Lough Erne (Trannish)	Upper Lough Erne	H325290	ULET1	23/6/07	98	H34270 30830	105	Fat Livingstone	M & C
Kilroosky	Magheraveely Marl Lakes	H495274	KILR1	25/6/07	310	H49368 27315	152	Fat Livingstone	M & C
Knockballymore C	Magheraveely Marl Lakes	H481271	KNOC1	25/6/07	205	H47995 27075	157	Fat Livingstone	M & C
Meenatully Lough	Pettigoe Plateau	G999653	MEEN1	21/6/07	220	G99892 65226	100	Fat Livingstone	M, C & D
Lough Rushen	Pettigoe Plateau	H019662	RUSH1	20/6/07	210	H01728 66013	107	Fat Livingstone	M, C & D
Glenbower Lough	Slieve Beagh	H549446	GLEL1	23/6/07	250	H54850 44552	35	Fat Glew	D
Lough Atona	Cuilcagh Mountains	H110292	ANON1	15/7/06	670	H11014 29161	25	Fat Glew	D

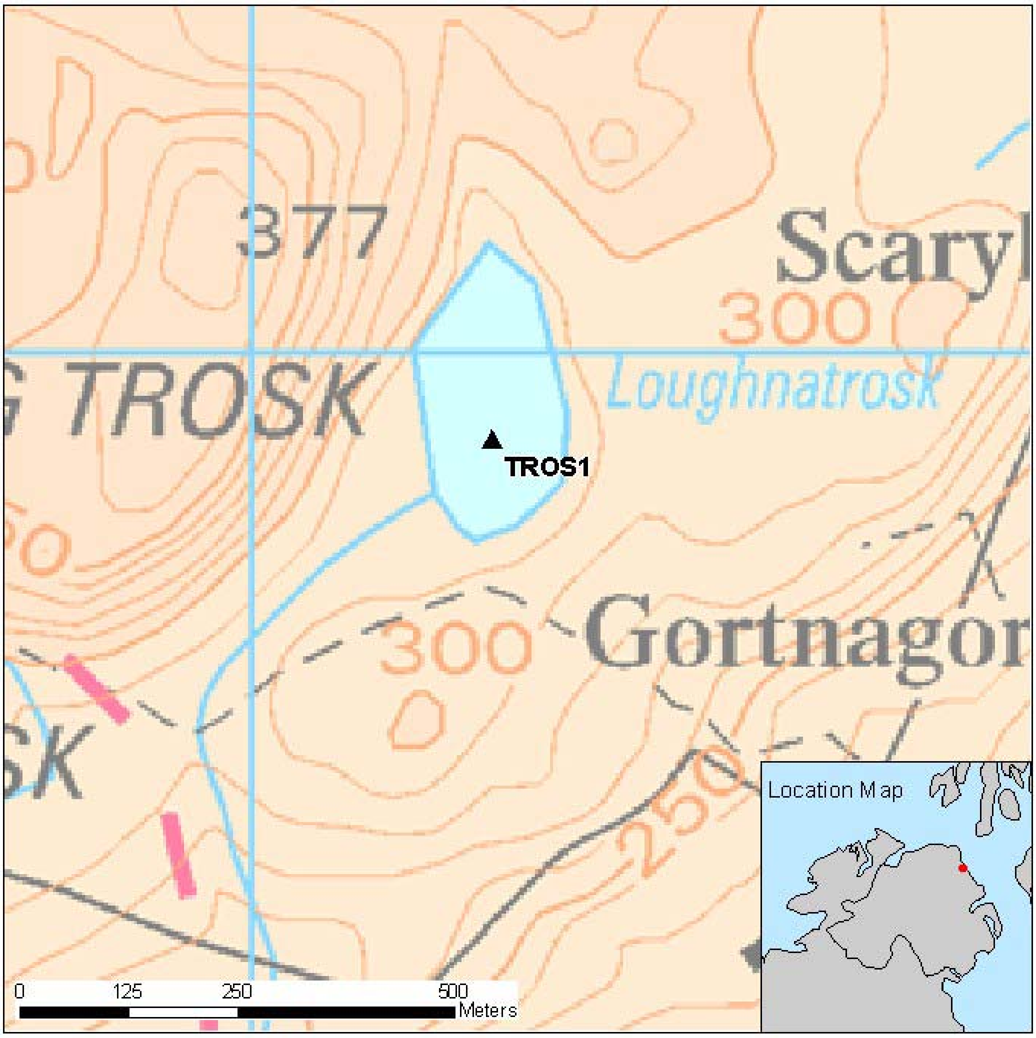
Garron Plateau

Two sites were sampled on the Garron Plateau (Table 1, Figure 1), Loughnatrosk and Loughgarve.

Loughnatrosk

Loughnatrosk lies in a depression below Big Trosk on the eastern lip of the Garron Plateau. It differs from many of the other lakes on the Plateau by having more alkaline waters and an extensive and relatively rich wetland margin along the west shore. The east shore is more exposed and grazing has limited the growth of marginal vegetation. Loughnatrosk is classified as: Annex 1 type: H3130: Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea.*

Figure 2 Map of Loughnatrosk with core location.

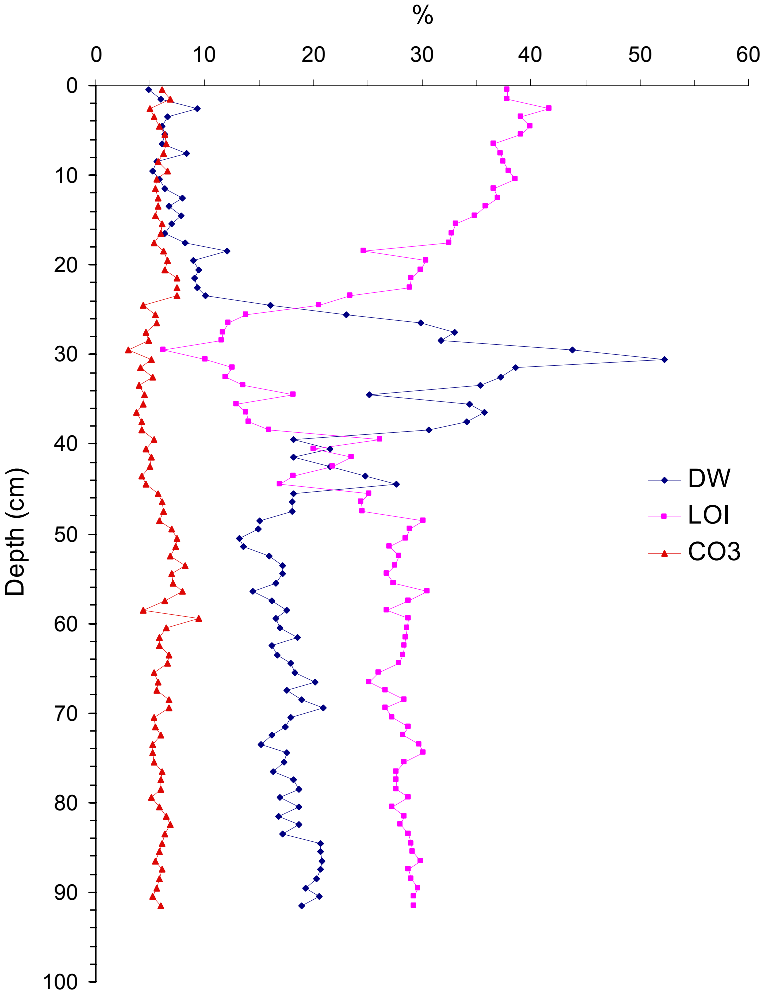


The surface area of the lough is approximately 3.50 ha (4.2 ha in UKLakes). The western shore has a significant area of boggy wetland which has resulted in a slight reduction in the total area of open water by a natural process of hydroseral development. The water chemistry of Loughnatrosk is typical of a mesotrophic lough, having circum-neutral pH and relatively low nutrients (recorded for 3 samples) and ionic concentration (Goldsmith *et al*. 2008). The aquatic flora consists of a shallow water zone (10-100 cm) along the east shore with *Littorella uniflora* dominant and *Chara virgata* and *Nitella opaca* both frequent. *Nitella opaca* then dominates throughout the deeper open water to the maximum depth of the lake (1.70 m). *Potamogeton natans* formed extensive beds from 90 cm to the maximum depth at the northern and southern ends and *P. perfoliatus,* and *M. alterniflorum* were common in the open water. *P. berchtoldii* was also common, but mainly confined towards the west margin. The wetland zone along the west shore ended abruptly with either *Phragmites australis* or *Menyanthes trifoliata* at the outer edge where the water depth drops in most parts to over 60 cm deep. *Utricularia minor* was common within the wetland vegetation. A small bed of *Sparganium angustifolium* occurred towards the southern end of the lough at approximately 140 cm depth. The mean TP is only just below the maximum target value set for mesotrophic loughs and the summer value was well above the target concentration (20 µgl^{-1} JNCC 2005) and well in excess of the concentration obtained in the summer of 1988. These results suggest the site has become enriched in recent years, which is of particular concern in light of the decline or loss of the *Groenlandia densa*. (Goldsmith *et al*. 2008).

TROS1 lithostratigraphy

The details of coring depth and location for TROS1 can be found in Table 1 and Figure 2. TROS1 had a number of distinguishing features which can be seen in Figures 3. The base of the core from 92 cm to around 45 cm was stable with a dry weight of around 15%, 30% LOI and 5% carbonate content. Above 45 cm % LOI fell sharply to <10% at 30 cm, there was a concomitant increase in DW to > than 50% at 30 cm, % carbonate remained stable at this time. Above 30 cm there was a sharp fall in DW and increase in LOI to 25 cm to 10% and 30% respectively. From 25 cm to the surface %LOI increased slowly to around 40% and %DW decreased gradually to 6% at the surface.

Figure 3 Lithostratigraphy of TROS1



TROS1 chronology

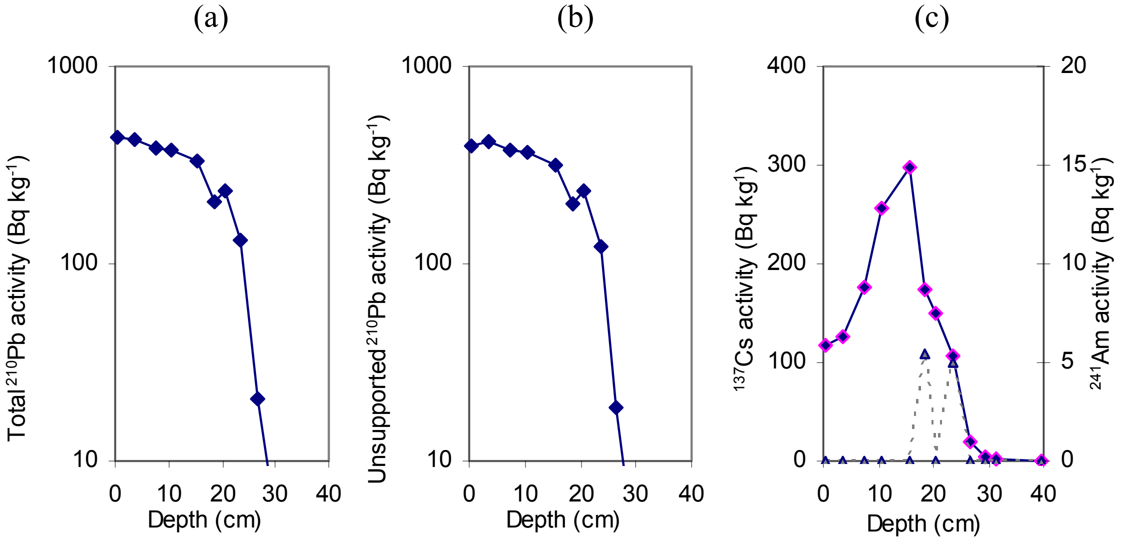
Lead-210 Activity

Total 210Pb activity and supporting 226Ra reached equilibrium at a depth of 30 cm. Unsupported 210Pb activities declined irregularly with depth (Fig 4), with the highest activity at 3.5 cm. There was little net decline in unsupported 210Pb activities in the top 10 cm of the core. In the 20-30 cm section, unsupported 210Pb activities decline more or less exponentially with depth. These results suggest a relatively uniform sedimentation rate between 20-30 cm with an increase in sedimentation rate from 10 cm to the surface.

Artificial Fallout Radionuclides

The 137Cs activity versus depth shows a single peak at 15.5 cm, but with relatively high 137Cs activities in between 10-16 cm. These relatively high 137Cs values suggest that they are derived from the 1986 Chernobyl accident, and thus the 1986 layer may reside in the 10 -16 cm section. Traces of 241Am were detected at 18.5 cm and 23.5 cm, implying the 1963/64 layer is in 18 – 24 section, but it is not possible to identify the 1963/64 depth with any certainty.

Figure 4 Fallout radionuclide concentrations in the Loughnatrosk core TROS1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth



Summary

Use of the CIC model was precluded by the non-monotonic variation in unsupported ^{210}Pb activity in the core. ^{210}Pb chronologies calculated using the CRS dating model put the 1963/4 layer in 18 cm, which is in agreement with the ^{241}Am record, and date the 1986 layer at 11 cm, which is the region of the flat peak of ^{137}Cs activities at 10-16 cm section. The CRS model calculated sedimentation rates using unsupported ^{210}Pb data show that sedimentation rates are relatively stable from the 1890s up to the 1970s, but the sedimentation rates have been significantly increased in the last few decades (Figure 5, Table 2)). The ^{210}Pb dating appears to have been relatively successful and thus the dates back to 1910 at least can be ascribed with some confidence. The data suggest a relatively low accumulation rate prior to 1950 of less than 2mm yr^{-1}, which thereafter increases to the present. By using the accumulation rate from the lower parts of the core it is possible to extrapolate dates for the entire core. These extrapolated dates are a guide only and cannot be interpreted with any certainty. This rough estimate would give the base of the core a date of at least 1500 AD, and the boundary between zones 1&2 in the macrofossil profile as 1700 and around 1750 for the cladoceran and diatom stratigraphies.

Figure 5 Radiometric chronology of the Loughnatrosk core TROS1 showing the CRS model ^{210}Pb dates and sedimentation rates.

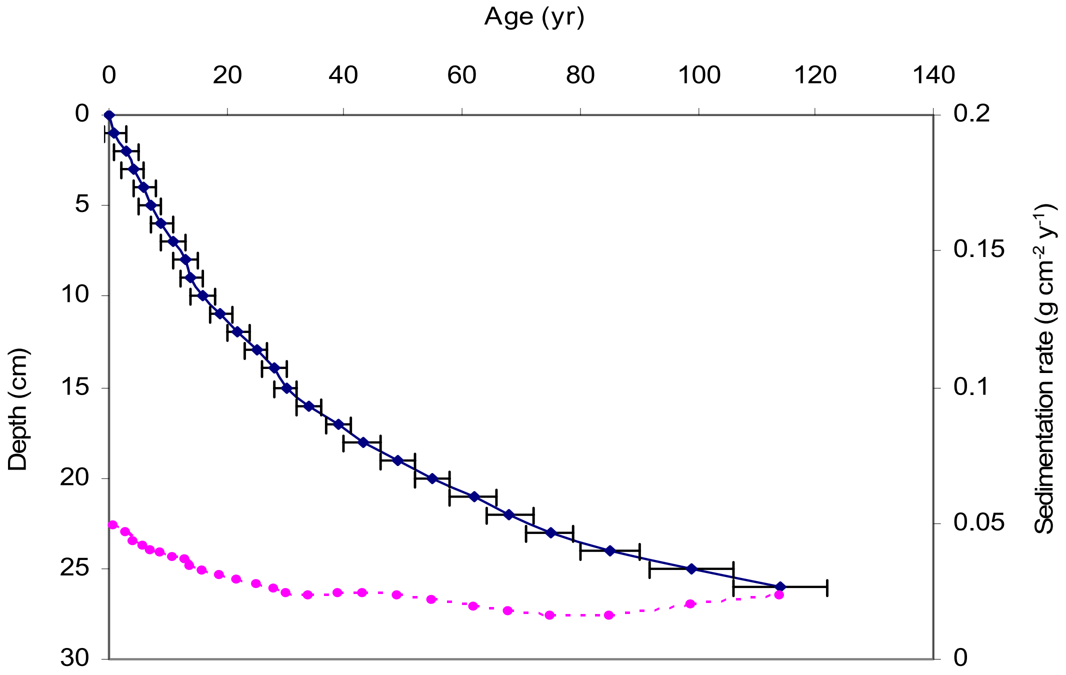


Table 2 210Pb chronology of the Loughnatrosk core TROS1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2007	0				
1	0.0583	2006	1	2	0.0487	0.783	13.1
2	0.1213	2004	3	2	0.0461	0.725	11.5
3	0.1841	2003	4	2	0.0434	0.666	9.9
4	0.2498	2001	6	2	0.0414	0.626	9.5
5	0.3182	2000	7	2	0.0402	0.604	10.1
6	0.3865	1998	9	2	0.0389	0.581	10.8
7	0.4549	1996	11	2	0.0376	0.559	11.4
8	0.5222	1994	13	2	0.0361	0.527	11.3
9	0.5885	1993	14	2	0.0343	0.486	10.5
10	0.6548	1991	16	2	0.0325	0.445	9.7
11	0.7277	1988	19	2	0.0308	0.408	9.6
12	0.8073	1985	22	2	0.0291	0.375	10.3
13	0.8869	1982	25	2	0.0274	0.342	11
14	0.9665	1979	28	2	0.0257	0.309	11.6
15	1.0461	1977	30	2	0.024	0.276	12.3
16	1.1387	1973	34	2	0.0234	0.25	12.2
17	1.2443	1968	39	2	0.0237	0.232	11.5
18	1.3499	1964	43	3	0.0241	0.214	10.7
19	1.4661	1958	49	3	0.0233	0.193	11
20	1.5929	1952	55	3	0.0213	0.168	12.2
21	1.7197	1945	62	4	0.0193	0.144	13.5
22	1.8466	1939	68	4	0.0174	0.12	14.7
23	1.9734	1932	75	4	0.0154	0.095	16
24	2.1616	1922	85	5	0.0161	0.08	18.7
25	2.4112	1908	99	7	0.0196	0.075	23
26	2.6607	1893	114	8	0.023	0.069	27.3

TROS1 biological data

Summary macrofossil results for TROS1 comprising a selection of fossils of generally submerged species which summarise the major floristic changes along the length of the core are shown in Figure 6. Shifts in the cladoceran assemblages can be seen in Figure 7 and diatoms in Figure 8.

TROS1 plant macrofossils

Zone 1 (80-55 cm)

The samples in zone 1 were dominated by large numbers of *Ranunculus* subgenus *batrachium* seeds and seed fragments, oospores of *Nitella* (morphotype A) and the remains *Gleotrichia*, a colonial alga. Oospores from another *Nitella* morphotype (B) were also present in one sample at 70cm. Furthermore, this zone also contained the remains of numerous broad and fine leaved *Potamogeton* species, which tended to increase in abundance towards the top of the zone*. Lobelia* seeds were also present throughout the zone as were *Chara* oospores of morphotype A.

Zone 2 (55-20 cm)

The high diversity and abundance of the *Potamogeton* species remains continued in zone 2. Megaspores of *Isoetes lacustris* appeared in one sample at 24cm but were absent throughout the rest of the core. Oospores of *Nitella* morphotype A remained abundant within zone 2 whilst *Chara* oospores morphotype A increased dramatically. There was a corresponding decrease and disappearance of *Ranunculus* subgenus *Batrachium* seeds*, Lobelia* seeds and *Gleotrichia* remains.

Zone 3 (20-0 cm)

Aquatic/submerged species diversity in this zone was greatly reduced in comparison to the lower sections. Whilst *Nitella* morphotype A oospores persisted there was a complete absence of *Ranunculus* subgenus *Batrachium* and *Lobelia dortmanna* seeds from zone 3*.* Oospores of *Chara* morphotype A were absent in the top sample of the zone. Above 20 cm broad leaved *Potamogeton* remains disappeared, in contrast the fine leaved species increased in abundance. *Gleotrichia* remains were also absent

Figure 6 Summary stratigraphy for selected plant macrofossils for TROS1

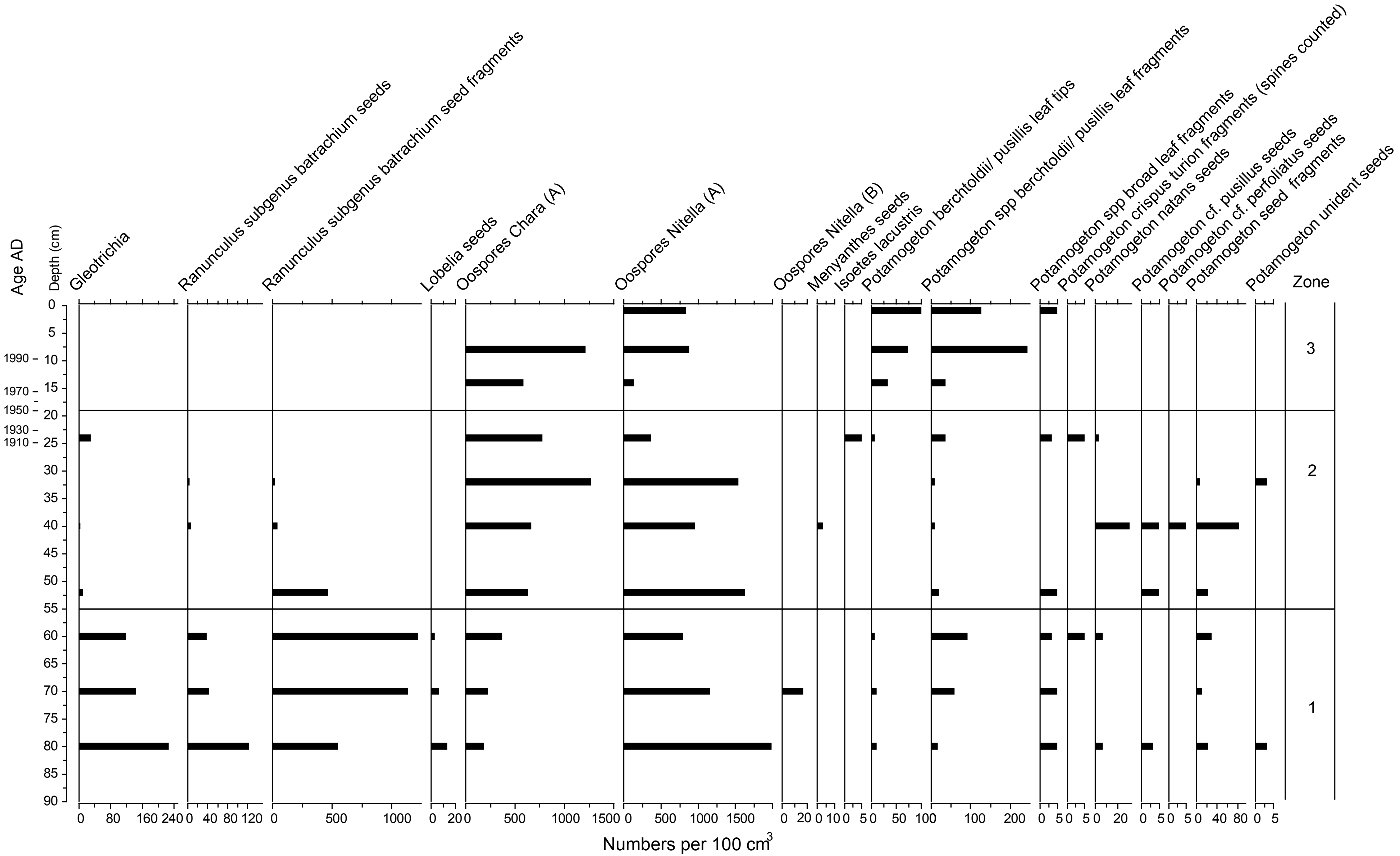
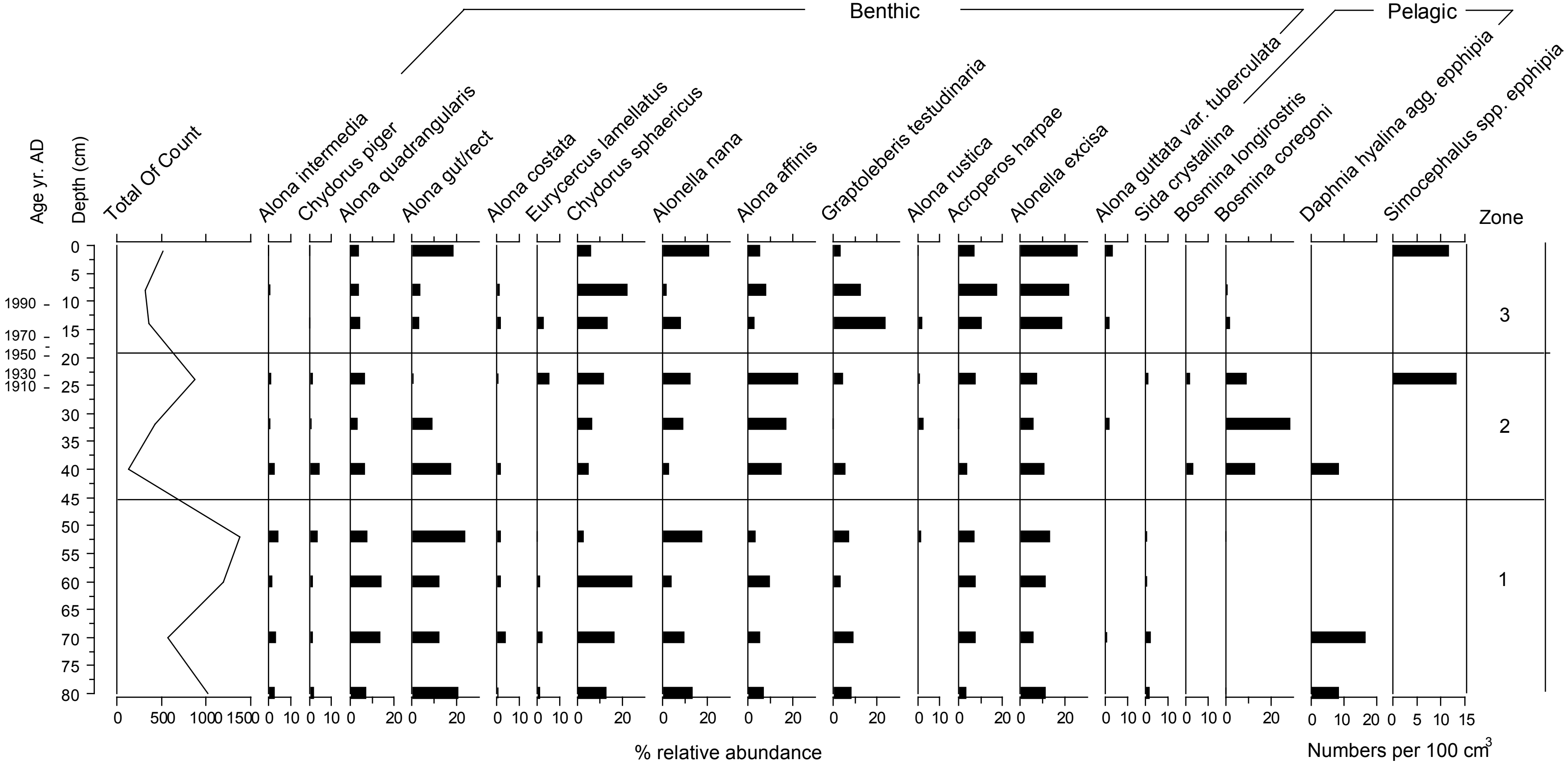


Figure 7 Summary cladoceran stratigraphy for TROS1



TROS1 cladoceran stratigraphy

The stratigraphy of selected cladoceran remains from TROS1 can be seen in Figure 7.

Zone 1 (80-45 cm)

This zone was characterised by the dominance of benthic taxa such as *Acroperus harpae, Alona intermedia* and *Graptoleberis testudinaria*. In addition, ephippia of *Daphnia hyalina* agg. were present at the base of the sequence, in relatively low numbers.

Zone 2 (45-20 cm)

There was a shift in the assemblage above 45 cm where the relative abundance of the plant-associated species such as *G. testudinaria* and *A. harpae* significantly decreased. There was a concurrent increase in the relative abundance of the pelagic cladoceran *Bosmina coregoni* and the more generalist taxa *Alona affinis* from 45 to 20 cm.

Zone 3 (20-0 cm)

Above 20 cm there was a shift to a community more akin to that of zone 1. The abundance of *B. coregoni* fell sharply and then disappeared. *A. harpae*, *G. testudinaria*, *Alonella excisa* and *Chydorus sphaericus* all increased their relative abundance. Epphipial remains of the plant-associated species *Simocephalus* were present above 24cm, whilst *Daphnia hyalina* agg. did not return in any significant number.

TROS1 diatom stratigraphy

Zone 1 (80-45 cm)

Zone 1 was dominated by various benthic *Fragilaria* (sensu lato) species, including *Staurosirella pinnata, Staurosira construens, Pseudostaurosira brevistriata, Staurosira construens* var. *venter*. Other species present, in smaller abundances, were *Cyclotella* cf *radiosa* (dissolved), *Cocconeis placentula*, *Navicula* cf. *schadei,* and *Achnanthes* (sensu lato) species (*Planothidium frequentissimum* and *Achnanthidium minutissmum*).

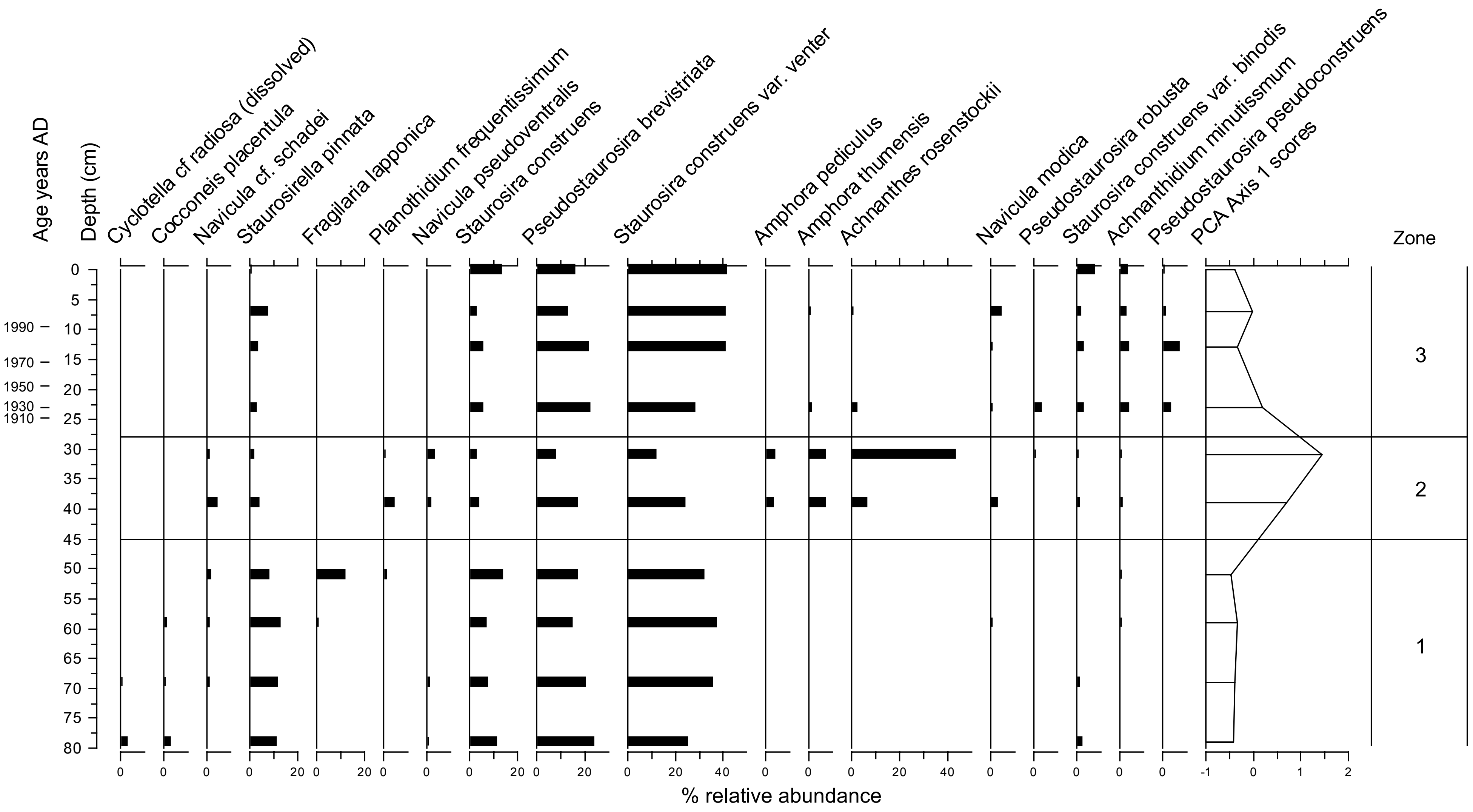
Zone 2 (45-27 cm)

In zone 2 most of the *Fragilara* (sensu lato) species (including *Staurosirella pinnata, Staurosira construens, Pseudostaurosira brevistriata* and *Staurosira construens* var. *venter*) decreased in abundance with corresponding increases in *Amphora pediculus, Amphora thumensis* and *Achnanthes rosenstockii* with the latter contributing to the higher PCA axis 1 scores.

Zone 3 (45-0 cm)

Zone 3 resembles the assemblage in zone 1 with increases in *Fragilara* (sensu lato) species and decreases in the *Amphora* species and *Achnanthes rosenstockii.* There were also slight increases in *Achnanthidium minutissmum* and *Pseudostaurosira pseudoconstruens*.

Figure 8 Summary diatom stratigraphy for TROS1



TROS1 interpretation

There was relatively good agreement in the zonation of all three biological records for TROS1, indicating a relatively coherent change in the ecosystem structure and function through time. There was, however, some disagreement between the different records, the diatom and cladoceran records having the boundary of zones 1 & 2 a little higher up the core than the macrofossil record. Given the relatively low resolution of analysis in the core (10 samples) the zones can be treated as analogous between the biological groups.

Macrofossil analysis from a single core does not provide a complete picture of the macrophyte flora, instead it provides information on the temporal dynamics of the submerged flora of a site (Davidson *et al*. 2005). The top sample from TROS1 compares relatively favourably when compared with data from the most recent plant survey (Table 3), with *Nitella* spp., fine and broad leaved *Potamogeton* remains found. Surface sediments are normally unconsolidated and are thus, not ideally suited for macrofossil analysis, in particular when accumulation rates are high as they appear to be here. This may explain the absence of *Chara* oospores from the uppermost samples, despite its abundance in the contemporary survey, as the larger/heavier oospores of *Chara* may have sunk through the unconsolidated uppermost sediments. The other species not represented were either rare, such as *Sparganium angustifolium*, or like *Littorella uniflora* do not leave macro-remains.

Table 3 Contemporary aquatic macrophyte community composition for Loughnatrosk

Submerged and floating vegetation	% occurrence 2006 (n=65)*	DAFOR 1988 (NILS)
Callitriche stagnalis	+	O
Chara virgata	32	+
Groenlandia densa		D
Lemna minor		R
Littorella uniflora	26	F
Myriophyllum alterniflorum	23	A
Nitella opaca	66	?
Potamogeton berchtoldii	15	F
Potamogeton natans	18	F
Potamogeton perfoliatus	23	A
Potamogeton polygonifolius	+	
Sparganium angustifolium	3	
Utricularia minor	+	O

* Based on presence / absence data from all vegetated plots in the CSM (JNCC 2005) wader and boat based surveys
A "+" denotes the presence of a species, but which was not recorded within the survey transects
A "?" is given where identification to species level was not achieved in the 1988 survey data.

The biological remains from TROS1 suggest that the site has undergone some fairly substantial change, in particular in macrophyte flora over the, at least 500 year, period represented by the core. The shifts in the cladoceran and diatom stratigraphies were in relatively good agreement, with zone 1 dominated by benthic flora and fauna respectively. The macrofossil record indicated a rich submerged macrophyte flora in zone 1 with *L. dortmanna,* abundant *Ranunculus* subgenus. *Batrachium*, with a very large number of seeds and fragments found, *Chara*, *Nitella* and a number of species of *Potamogeton*.

There was a significant change the between zones 1 and 2 with the decline of *R.* subgenus *Batrachium* and an increase in *Chara* and *Nitella* oospore abundance along with a shift in the *Potamogeton* flora. There was one level with very high numbers of *Potamogeton* seeds (40-41 cm) suggesting that perhaps there was an increase in the abundance of pondweeds at this time with at least *P. perfoliatus*, *P. natans* & *P. pusillus* present. The changes in the diatom assemblage were relatively difficult to interpret, the PCA axis 1 score reflects a relatively large shift in diatom assemblage with an increase in the relative abundance of a number of *Amphora* species, all of which are plant-associated taxa (Sayer *et al.* 2001) and *Achnanthes rosenstockii*. The changes in the cladoceran assemblage may, however, provide some insight into changes in ecological function associated with the alterations in macrophyte flora. The increase in the relatively large bodied planktonic *Bosmina coregoni* and the generalist taxa *Alona affinis* along with the decline in more benthic species such as *G. testudinaria* and *A. harpae* suggest an increase in the planktonic productivity of the site relative to benthic production, a phenomenon associated with increased nutrient levels (Vadeboncoeur *et al*. 2005). The increases in the organic matter of the sediments (% LOI, Figure 3) accord well with an increase in productivity at this time. Without a detailed knowledge of the history of the catchment the source of any increase in nutrients at this time is a matter for speculation.

In zone 3 the cladoceran and diatom assemblages both shifted back to assemblages similar to those in the basal zone 1. There were, however, some subtle differences from the assemblage in zone 1 with *Alonella excisa*, a benthic species, more abundant in the cladoceran record and *Pseudostaurosira pseudoconstruens*, *Achnanthidium minutissmum* and *Staurosira construens* var. *binodis* more prevalent in the diatom assemblage. The macrofossil record did not indicate a return to the community of zone 1. There was the continued presence of both *Chara* and *Nitella* oospores but the macrofossil record suggested a shift from a relatively diverse *Potamogeton* assemblage to one where fine-leaved species, generally more tolerant of eutrophication are dominant (Van de Berg *et al.* 1999).

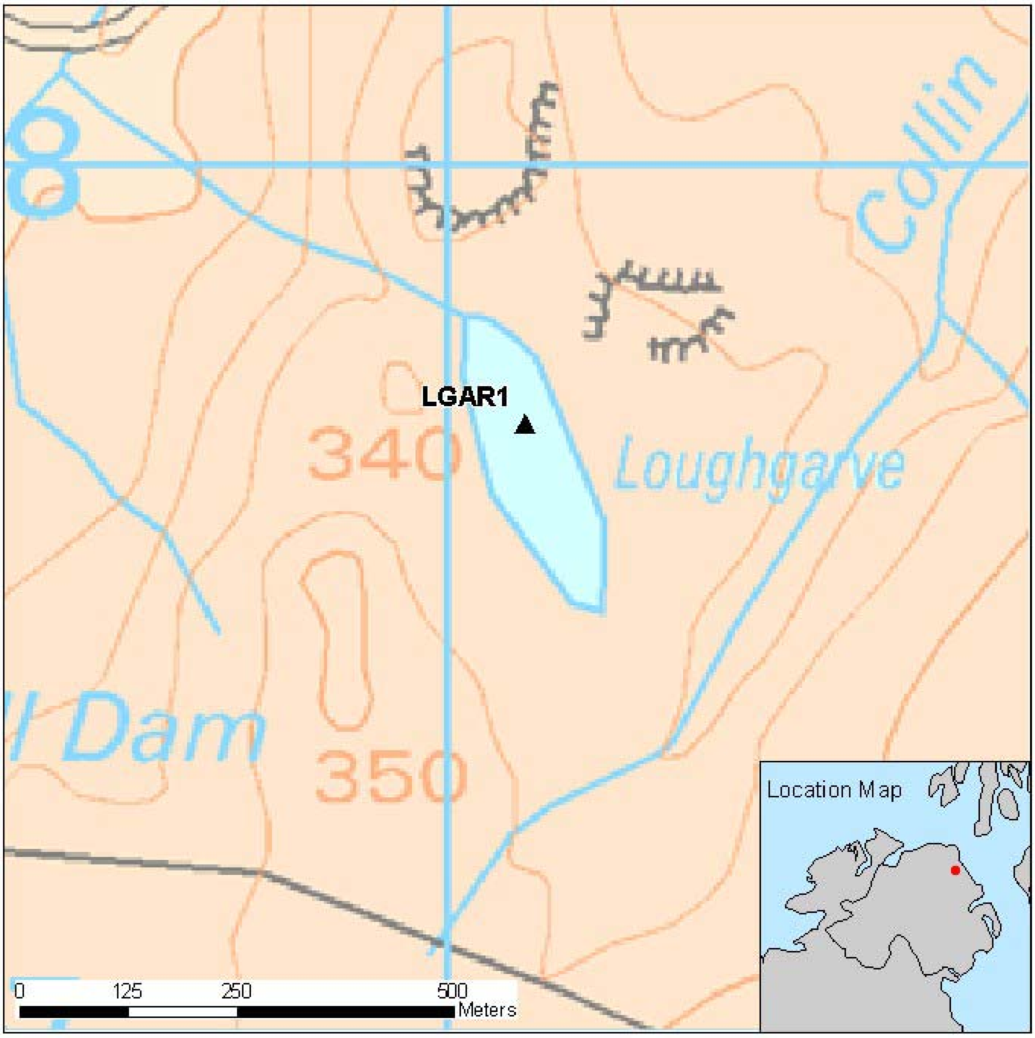
To summarise Loughnatrosk appears to have undergone a fairly profound shift in macrophyte flora over the time period represented by the sediment core, about 500 years. It initially had a more meso-oligotrophic flora containing *L. dortmanna*, *Chara* and *Nitella* species, abundant *Ranunculus* subgenus *Batrachium* species and a diverse *Potamogeton* flora including broad and fine leaved species. After 1700, productivity may have risen, suggested by the increases in %LOI and planktonic cladocerans, which may have resulted in the loss of the more oligotrophic macrophyte species. The system appears to have then been relatively stable until around the 1950 where sediment accumulation rates rose and there was shift towards more fine-leaved *Potamogeton* species, although the oospore numbers for both *Chara* and *Nitella* suggest there are still healthy populations at the site.

Loughgarve

Loughgarve is a very shallow (0.75 m) upland lough lying within a catchment of extensive rough grazing with a surface area of 2.5 ha. Classified as: Annex 1 type: H3130: Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*.

Loughgarve is very shallow and therefore is unlikely to exhibit some of the characteristic species or structure normally associated with deeper oligo-mesotrophic lakes (e.g. *Isoetes lacustris, Sparganium angustifolium* and deep-water *Potamogeton* spp). Much of the lake bed is comprised of very soft, organic sediments which are easily disturbed by water movement and therefore likely to provide a poor rooting medium for plants. *L. uniflora* was only found growing submerged in two locations; one between boulders and the other in an area of more consolidated mineral silts. This species was, however, common above the water line where it was rooted in gravels. *Utricularia minor* was only found in one location. Other submerged macrophytes and charophytes were found mainly in very shallow water where sediments were less flocculent. The *Stratiotes aloides* and *Chara hispida* reported from the lake in 1990 (NILS) were not recorded in this survey and seem unlikely species for this lake type. (Goldsmith *et al*. 2008). Being so shallow, the majority of the lake was colonised by sparse emergent vegetation, with *Equisetum fluviatile* and *Schoenoplectus lacustris* in the open water and *Phragmites australis* and *Carex rostrata* restricted more to the margins. Despite the favourable chemical conditions the depauperate nature of the macrophyte flora means the site was classified as unfavourable in the most recent assessment of condition (Goldsmith *et al*. 2008 under the CSM (JNCC 2005)). The current study will place this assessment within an historical context.

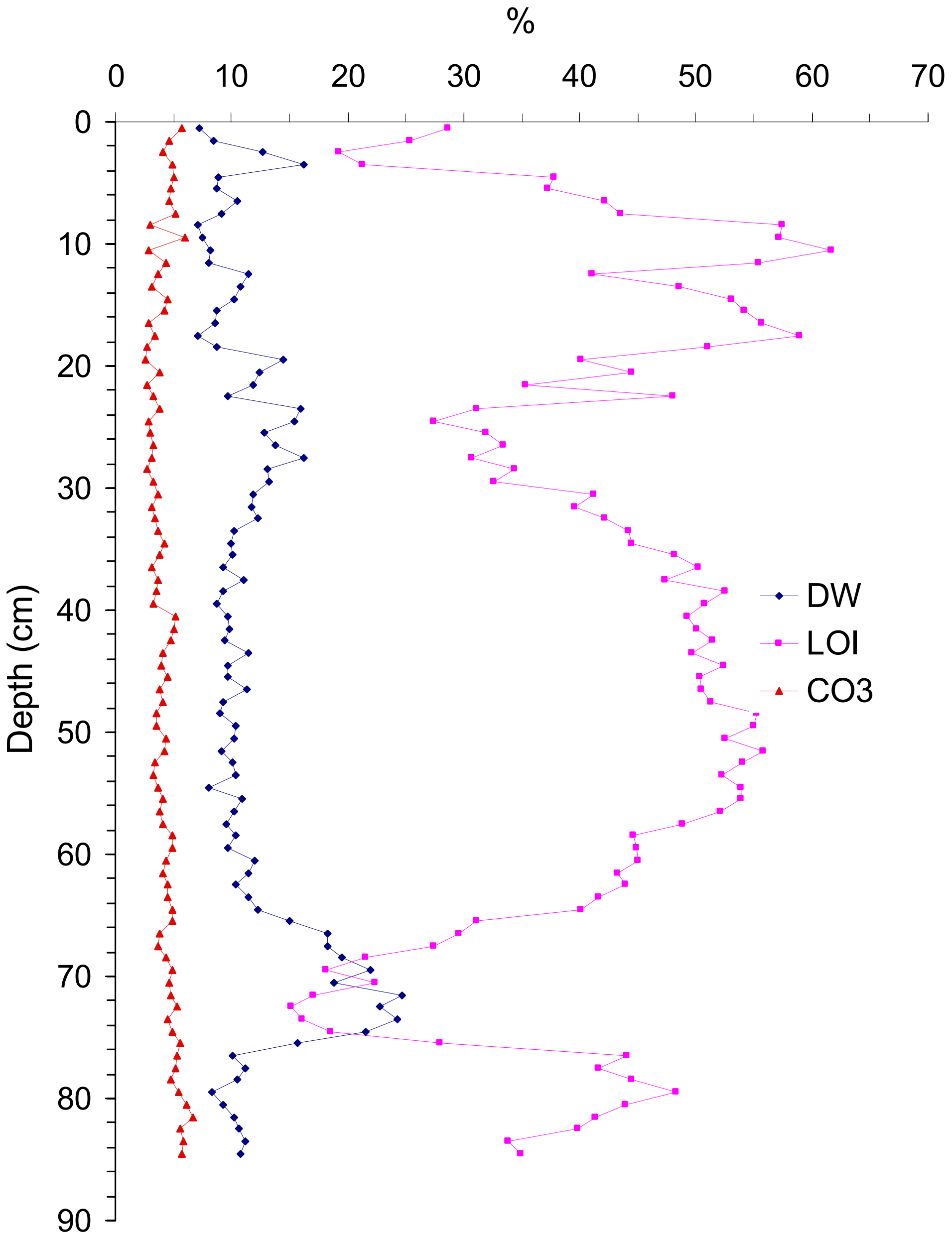
Figure 9 map of Loughgarve and coring location



LGAR1 lithostratigraphy

Details of LGAR1 and location can be found in Table 1 and Figure 9. There was considerable variation in the lithostratigraphy in LGAR1 but in general there was high organic content (%LOI) and low dry weight and carbonate (Figure 10). The high %LOI at the base fell very sharply at around 80 cm from 50% to around 10% at 75 cm with an associated rise in dry weight from 10 to 25%. Above 75 cm there was a more gradual rise to > 55% at 55 cm up to 40cm followed by a gradual fall to 25% at 25 cm. There was then a period of quite abrupt variation in %LOI as it rose and fell sharply with a general trend upwards to around 60% at 10 cm. This was followed by a steady and regular fall to 20 to 30% at the surface.

Figure 10 Lithostratigraphy of LGAR1



LGAR1 chronology

Lead-210 Activity

Sedimentation rates appear to be slow in LGAR1 as equilibrium between total 210Pb activity and the supporting 226Ra occurred at a depth of 5 cm (Figure 11). The unsupported 210Pb activities had little net decline in the surface 3 cm, but decline more or less exponentially downwards to the equilibrium depth, suggesting a relatively slow change in sedimentation below 3 cm, but a rapid increase in the surface.

Artificial Fallout Radionuclides

The 137Cs activity versus depth shows a single well-resolved peak at 2.5 cm. This peak is derived from 1963/64 fallout maximum from the atmospheric testing of nuclear weapons, and it is supported by the presence of traces of 241Am at about the same depth. The very high 137Cs activity derived from the atmospheric testing of nuclear weapons suggests that sedimentation rate of the core during the testing time is very low.

Figure 11 Fallout radionuclide concentrations in the Loughgarve core LGAR1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.

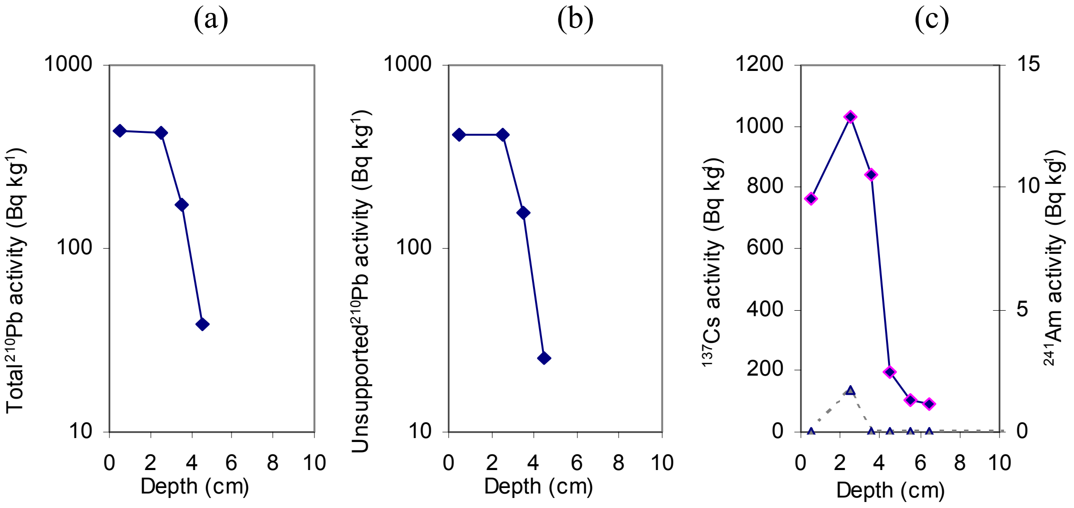


Table 4 210Pb chronology of the Loughgarve core LGAR1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2006	0				
0.5	0.0419	2002	4	2	0.0117	0.094	6.6
1	0.11	1993	13	2	0.0096	0.076	6.9
1.5	0.1781	1984	22	2	0.0075	0.058	7.2
2	0.2462	1974	32	2	0.0054	0.041	7.5
2.5	0.3143	1960	46	3	0.0038	0.028	9.7
3	0.3824	1939	67	4	0.0031	0.022	14.6
3.5	0.4505	1919	87	6	0.0023	0.016	19.5
4	0.5265	1874	132	6	0.0016	0.011	21.7
4.5	0.6024	1830	176	7	0.0009	0.006	24

Summary

The CRS and CIC models date the 1963/64 layer at c. 2.5 cm and 3 cm, respectively. 210Pb chronologies calculated using the CRS dating model (Appleby & Oldfield, 1978) is in good agreement with the 137Cs record, suggesting the CRS model is appropriate for this core, but not the CIC model. Sedimentation rates calculated using unsupported 210Pb show that sedimentation rates in this core are slow, but increase from 0.001 g cm-2 yr-1 at 4.5 cm to 0.012 g cm-2 yr-1 at the surface (Table 4). The dating for LGAR1 suggests an extremely slow accumulation with only 5 cm of sediment accumulating in the last 150 years. Given the nature of the site this seems highly unlikely and thus the dating model should be interpreted with caution.

LGAR1 biological data

Summary macrofossil results for LGAR1 comprising a selection of fossils of generally submerged species which summarise the major floristic changes along the length of the core are shown in Figure 12. Shifts in the cladoceran assemblages can be seen in Figure 13 and diatoms in Figure 14. There was good agreement between the major stratigraphic zones between the different biological groups.

LGAR1 plant macrofossils

Zone 1 (70-50 cm)

In the lowest sample, at 70cm, *Lobelia* seeds, *Chara* oospores morphotype A and *Potamogeton* cf *friesii* seeds occurred at their highest abundance. Large numbers of *Nitella* oospores morphotype A were also present within this sample, in conjunction with small amounts of *Isoetes lacustris* remains. Towards the top of the zone *Chara* oospores morphotype A, *Potamogeton* cf *friesii* seeds, *Nitella* oospores morphotype A and *Lobelia* seed remains decreased. In contrast, remains of *Isoetes lacustris* increased slightly. *Juncus* species and moss (primarily *Sphagnum*) contributed to the terrestrial vegetation in zone 1 and low numbers of *Selaginella* megaspores were also present.

Zone 2 (50-5 cm)

Isoetes lacustris and *Potamogeton* cf *friesii* remains disappeared in zone 2; *Lobelia* seeds occurred in the lowest sample in zone 2 but were not present thereafter. In contrast, *Nitella* oospores morphotype A occurred throughout the zone reaching their highest abundance between 25 and 30cm, and declined in abundance towards the top of the zone. *Chara* oospores morphotype A were also present within the samples at 25-30cm but absent from the remaining zone 2 samples. *Gleotrichia* first appeared in the record at 35cm and was present throughout most of zone 2. Moss remains were abundant within the lower section of zone 2 and generally decreased towards the top of the zone with a corresponding increase in *Juncus* seeds within the uppermost zone 2 samples. *Selaginella* megaspores were also present in varying abundances throughout zone 2. Of interest is that there is some evidence of burning at 18cm with charcoal and charred stems present.

Zone 3 (5-0 cm, post 1985AD)

Zone 3 contained the uppermost core sample only hosting the remains of *Isoetes lacustris* in very low numbers and a small numbers of *Nitella* oospores morphotype A. Small numbers of *Juncus* seeds, *Selaginella* megaspores and moss remains were also present within this zone.

Figure 12 Summary stratigraphy for selected plant macrofossils LGAR1

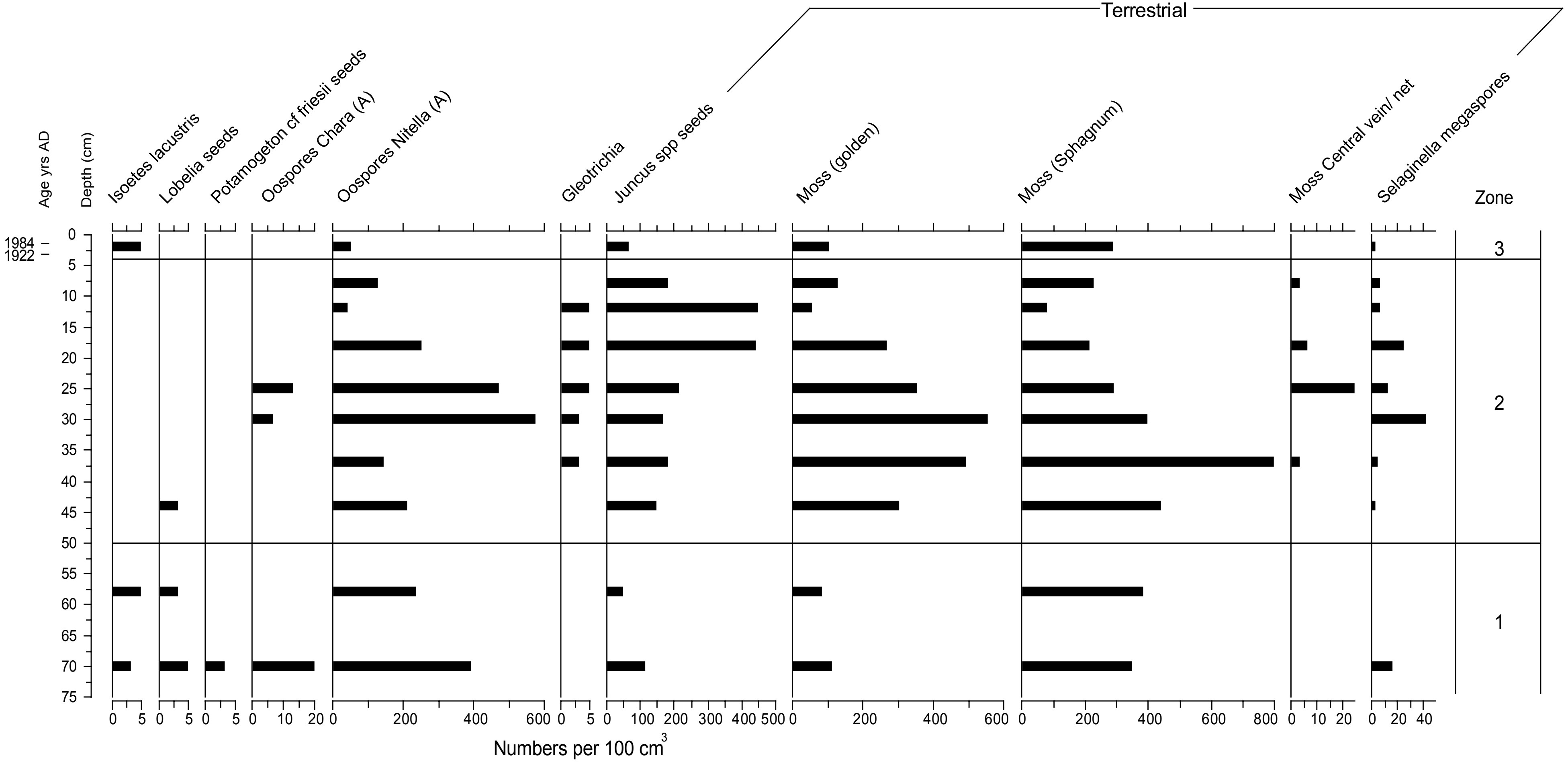
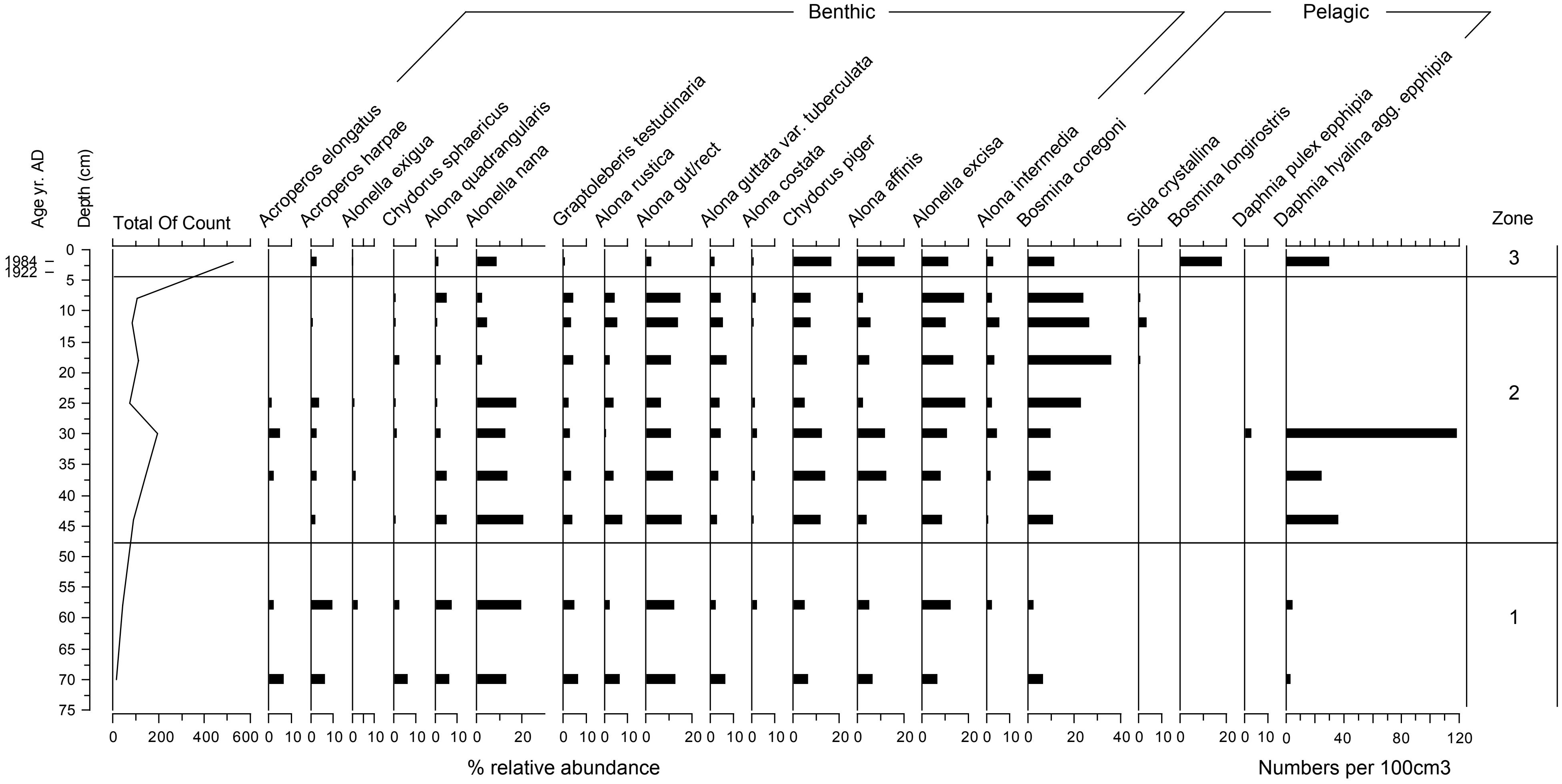


Figure 13 Summary cladoceran stratigraphy for LGAR1



LGAR1 cladoceran stratigraphy

The stratigraphy of the sub-fossil cladoceran profiles for LGAR1 (Figure 13) displayed the same zonation as plant macrofossils.

Zone 1 (70-50 cm)

The base of the sequence had a higher diversity of plant-associated and benthic species. No single species were dominant but A. *nana*, *G. testudinaria*, *Acroperus elongates* and *A. harpae* were fairly numerous as were small numbers of the pelagic species *B. coregoni*. In addition there were low numbers of *D. hyalina* agg. ephippia.

Zone 2 (50-5 cm)

The main change between zones 1 and 2 was an increase in pelagic species of cladocerans; in the lower part of the zone (50-30 cm) this was *D. hyalina* agg. ephippia above 30 cm *D. hyalina* ephippia disappeared and *B. coregoni* increased its relative abundance. The numbers of benthic and epiphytic species declined in this zone.

Zone 3 (5-0 cm, post 1985AD)

This zone consisted of the top-most sample only, in this sample there was a shift from *B. coregoni* to the smaller *Bosmina longirostris* and the reappearance of *D. hyalina* agg. ephippia. The assemblage was relatively species poor compared to lower samples with fewer benthic species with *Chydorus piger* and *Alona affinis* dominant.

LGAR1 diatom stratigraphy

The diatom stratigraphy (Figure 14) had slightly different zonation from the plant macrofossils and cladocerans with zone 1 finishing sooner but the general pattern was the same as the other biological groups.

Zone 1 (70-60 cm)

The lowermost sample is dominated by *Cymbella lapponica*, *Achnanthidium minutissimum* and *Brachysira vitrea*, with small numbers of *Encyonema gracilis, Staurosira construens* var. *venter* and *Fragilariforma virescens* var. *exigua* also present.

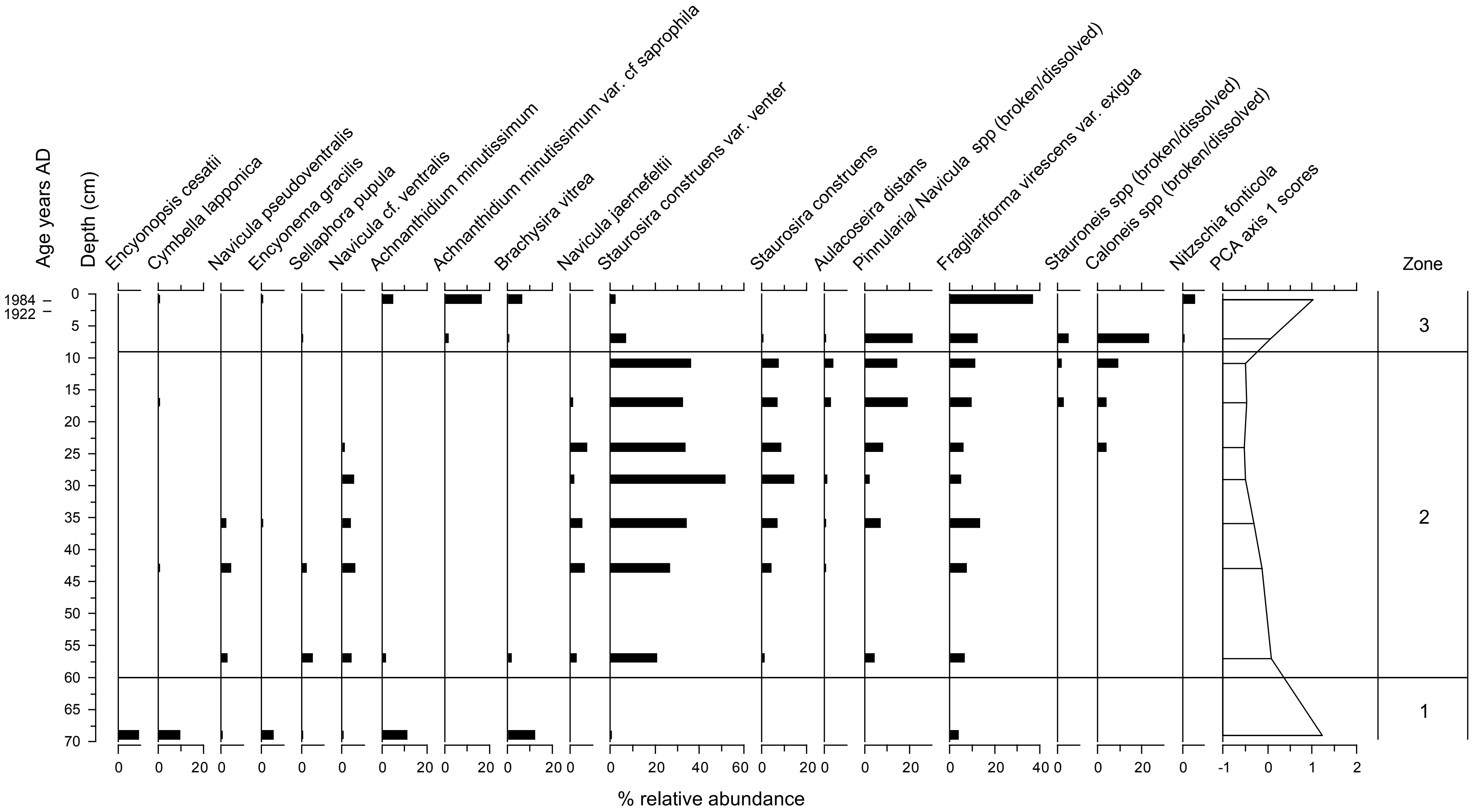
Zone 2 (60- 8 cm)

Zone 2 is dominated by *Staurosira construens* var. *venter* reaching a maximum abundance of 52% at 29 cm. *Staurosira construens* and *Fragilariforma virescens* var. *exigua* also attain relatively high abundances within this section of the core. There was some evidence of dissolution within this core (broken/dissolved valves of *Pinnularia/ Navicula*, *Caloneis* spp, *Stauroneis* spp), appearing to increase towards the top of zone 2. Abundances of *Brachysira vitrea, Achnanthidium minutissimum, Cymbella lapponica* are greatly reduced in this zone in comparison to zone 1. PCA axis 1 scores are lower in this zone than in zone 1 and decrease towards the top of the zone.

Zone 3 (8-0 cm)

Abundances of *Brachysira vitrea, Achnanthidium minutissimum, Achnanthidium minutissimum* var. *cf saprophila, Fragilariforma virescens* var. *exigua* and *Caloneis spp* (broken/dissolved valves) increase towards the top of the core, with a corresponding decrease in *Staurosira construens* var. *venter* and *Staurosira construens.* These shifts are reflected in the higher PCA axis 1 scores in zone 3, which also resemble the scores attained in zone 1.

Figure 14 Summary diatom stratigraphy for LGAR1.



LGAR1 interpretation

The numbers of macrofossil remains were relatively low within the core, with the exception of *Nitella* oospores which reached relatively high numbers in zones 1 and 2. The numbers of oospores in zones 1 & 2 were >500 per 100 cm^3 and likely reflect a relatively high cover of charophytes at those times (Zhao *et al*. 2006). The uppermost sample only had *Nitella* spp. which is not a particularly good reflection of the contemporary community when compared with the most recent survey (Table 5, Goldsmith *et al*. 2008). Plant abundance was, however, very low and the plant macrofossil technique has been shown not to record rare species very well (Davidson *et al.* 2005). Of note was the presence of *Isoetes lacustris* in the uppermost sample suggesting its occurrence in the lake in the relatively recent past when it has not been recorded in the last two contemporary surveys. The ^{210}Pb chronology of the site suggests an extremely slow sediment accumulation rate, it seems unlikely that this site has only accumulated 5 cm of sediment in *c.* 150 years and thus, the dating needs to be treated with caution.

Table 5 Contemporary aquatic macrophyte community composition for Loughgarve

Submerged and floating vegetation	**% occurrence 2006 (n=53)***	**DAFOR 1990 (NILS)**
Chara hispida		+
Chara virgata	6	?
Juncus bulbosus	2	O
Littorella uniflora	4	F
Myriophyllum alterniflorum	2	O
Nitella opaca	2	?
Potamogeton natans	9	O
Potamogeton polygonifolius	6	F
Stratiotes aloides		+
Utricularia minor	2	O

* Based on presence / absence data from all vegetated plots in the wader and boat based surveys
A "+" denotes the presence of a species, but which was not recorded within the survey transects
A "?" is given where identification to species level was not achieved in the 1988 survey data.

The combined data suggest a decline in the ecological quality of the site in the time period represented by the core with a loss of some macrophyte taxa and a loss of biological diversity. The different biological groups analysed are in good agreement on the timing and nature of change in Loughgarve. The base of the sequence, to which it is not possible to ascribe a date, suggests a relatively species rich community of submerged plants, for a more upland site, with *L. dortmanna*, *Chara* and *Nitella* species and at least one *Potamogeton* species, most likely *Potamogeton friesii,* although this is not recorded for this area of Northern Ireland. This is supported by the diatom assemblages in the basal section which had a higher diversity containing many epiphytic taxa, albeit at low abundances, such as *Cymbella* (sensu lato) spp. (inc. *Cymbella lapponica, Encyonema gracilis* and *Encyonopsis cesatii.* The cladoceran data also accord well with this interpretation with a number of plant associated benthic species present, such as *A. harpae* and *A. elongatus*, in addition *D. hyalina* agg. ephippia were present in low numbers indicating little planktonic productivity.

The shift in assemblages above 50 cm in the core suggests a decline in the diversity of the macrophyte flora of the site with the loss of *I. lacustris* and *L. dortmanna*. Contemporaneous with these losses was a dramatic increase in the abundance of the *Daphnia* ephippia, indicative of an increase in planktonic primary production. One theory for the decline in the condition of the site through time could be the sequential shallowing of the system through natural or anthropogenically accelerated sediment accumulation. The evidence does not, however, support this idea for the changes that occurred between zones 1 and 2, such as increased planktonic and the reduced benthic taxa are unlikely to have occurred if there had been a reduction in water level. Other drivers of this change might have been the increased availability of nutrients, or perhaps a change in water clarity by some other agent. Of interest in zone 2 there appeared to be an abrupt shift from dominance of the dominant component of the cladoceran plankton from *D. hyalina* to the smaller bodied *B. coregoni.* This shift occurred in concert with the fairly dramatic increase in *Nitella* oospore abundance and the appearance of *Chara* oospores in the record, suggesting some fairly profound shift in ecosystem structure and function at that time. Interesting though these shifts are it is difficult to identify what may have caused such a change, however a shift from *Daphnia* to *Bosmina* is often associated with increased zooplanktivorous fish predation (Brooks & Dodson 1965) and thus a change, or the initiation of fish stocking practice could have been the cause of these changes. The final change in the sub-fossil assemblages at the site may reflect decreasing water depth. The increase in *B. longirostris*, a species associated with shallower water and more turbid conditions may indicate an overall decrease in lake depth. Such a decrease may lead to sediment resuspension and a poor light-climate, possibly inhibiting plant growth at Loughgarve.

Upper Lough Erne

Three sites were sampled in the Upper Lough Erne catchment (Table 1, Figure 1), Mill Lough and Killymackan were selected for study but a core was taken in main lough in the Trannish areas during the 2006 field trip and some samples analysed to provide EHS with supplementary information.

Mill Lough

Mill Lough lies within semi-improved farmland and is surrounded by a number of different transitional vegetation zones from open water through to wet woodland on the northwest shore, fen meadow on the eastern shores and dense *Scirpo-Phragmitetum* communities around the southeast margin. The surface area of the lough is 34.4 ha. Classified as: Annex 1 type: H3150: Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation.

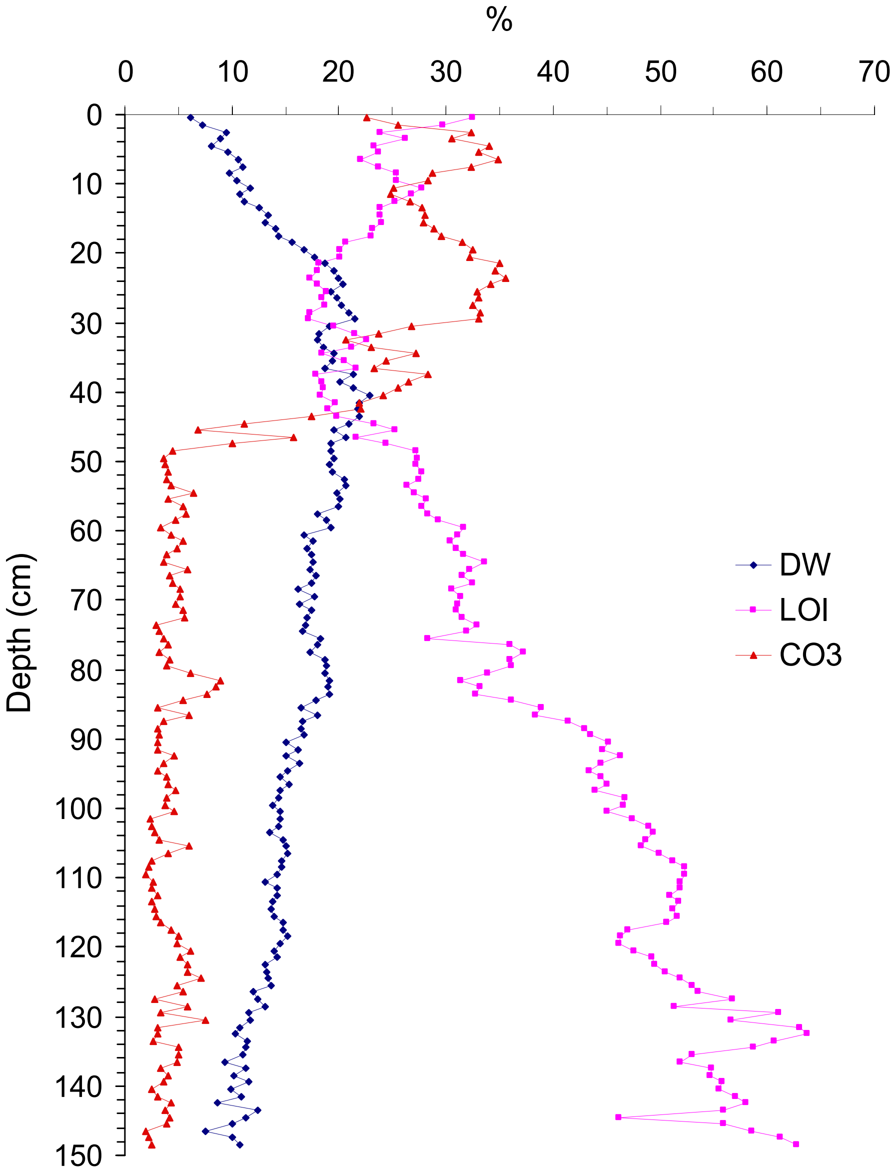
Mill Lough has an exceptional aquatic macrophyte assemblage with respect to the characteristic species as well as a rich marginal and emergent flora. The lough supports thirteen of the *Magnopotamion* and *Hydrocharition*-type species and 19 submerged and floating species in total. The occurrence of 8 different *Potamogeton* taxa in a water body of this size is extremely rare. Mill Lough is relatively shallow (9.3 m), high alkalinity, has low annual mean TP (23 μgl^{-1}) and chlorophyll *a* concentrations (11.1 μgl^{-1}), which is within the acceptable limit for high alkalinity lakes (15 μgl^{-1} Phillips 2005) and is thus, classified as “favourable” with respect to trophic status (Goldsmith *et al*. 2008). Whilst the site is in favourable condition it is classified as ‘at risk’ owing to the relatively large abundance of *Elodea canadensis*. It is unfortunate in the context of this study that *E. canadensis* leaves no sedimentary remains.

Figure 15 Map of Mill Lough with core location.

LMIL1 lithostratigraphy

The details of coring depth and location for LMIL1 can be found in Table 1 and Figure 15. LMIL1 had a number of distinguishing features which can be seen in Figures 16. At the base of the core from 150 cm to around 45 cm there was a steady and gradual decline in organic content, expressed as % LOI, from a very high >60% to 20%, with a concomitant increase in dry weight (DW). Above 45 cm %LOI did not vary greatly to 20 cm whereupon it gradually rose to around 25% at the surface, DW mirrored these changes. Carbonate content of the sediments was uniformly low from the base of the sequence to around 50 cm where there was a sharp increase from around 5% at 50 cm to >30% at 30 cm. Thereafter it varied between 25% and 35% to the surface of the core.

Figure 16 Lithostratigraphy for LMIL1



LMIL1 chronology

Lead-210 Activity

Equilibrium between total 210Pb activity and the supporting 226Ra occurred at a depth about 32 cm (Figure 17). The unsupported 210Pb activity can be divided into two sections: there was little net decline in unsupported 210Pb activities in the top 11 cm section, suggesting an increase in sedimentation rates; unsupported 210Pb activities declined more or less exponentially downwards from 11 cm to the equilibrium depth, suggesting a relatively uniform sedimentation in this section.

Artificial Fallout Radionuclides

The 137Cs activity versus depth showed a single well-resolved peak at 11.5 cm, also present were considerable traces of 241Am at 15.5 cm. The presence of 241Am is linked to the 1963 peak of fallout from the atmospheric testing of nuclear weapons, it is at different depth from the well-resolved 137Cs peak at 11.5 cm. It is possible that the 137Cs peak at 11.5 cm records the fallout from the 1986 Chernobyl accident, and due to the high levels, it obscures the 137Cs peak derived from the 1963 maximum in fallout resulting from atmospheric testing of nuclear weapons, which should appear at 15.5 cm where the 241Am maximum occurred.

Figure 17 Fallout radionuclide concentrations in the Mill Lough core LMIL1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.

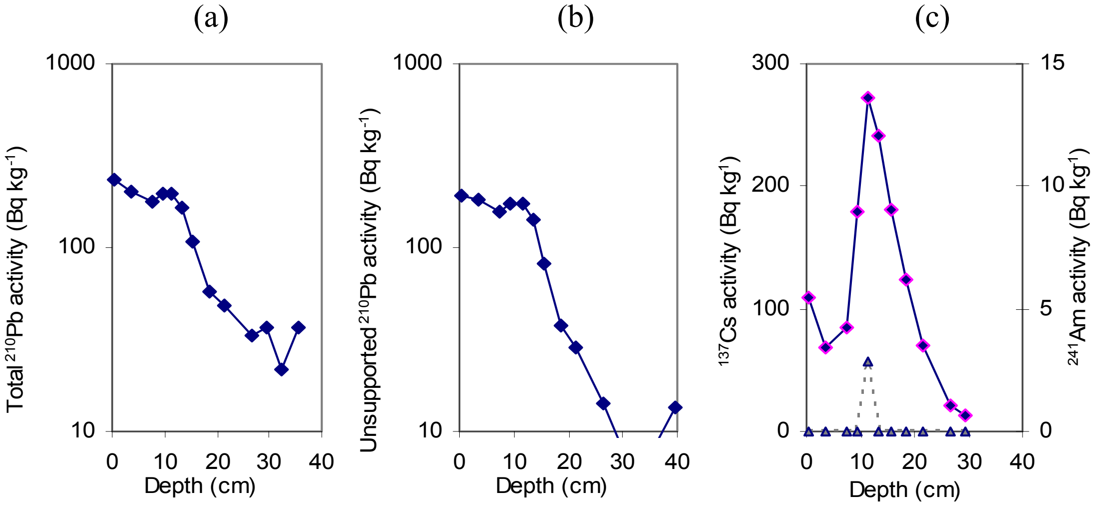
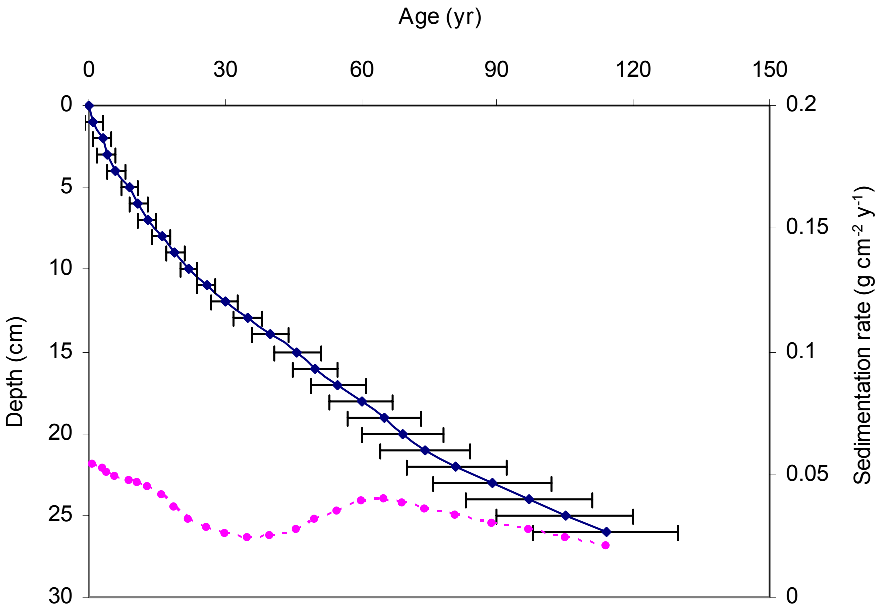


Figure 18 Radiometric chronology of the Mill Lough core LMIL1 showing the CRS model ^{210}Pb dates and sedimentation rates.



Summary

The non-monotonic variation in unsupported 210Pb activity in the top 11 cm precluded the use of the CIC model. 210Pb chronologies calculated using the CRS dating model put the 1963 layer at c. 15 cm, which is in good agreement with the 241Am record, and the 1986 layer at c. 10 cm, which is in good agreement with the 137Cs peak, suggesting the CRS model is appropriate for this core. The unsupported 210Pb flux was calculated to be 107.5 Bq m-2 y-1 in the core, a typical deposition rate for the region. Sedimentation rates calculated using unsupported 210Pb show that sedimentation rates are relatively uniform in 11 – 26 cm section, but increased in sedimentation from 11 cm upwards to the surface (Figure 18, Table 6). The radiometric dating of this core appears to have been successful with the chronology appearing sensible. If the accumulation rates at the bottom of the dated section of the sequence, i.e. 26 cm are extrapolated then it would suggest that the base of the core, around 120 cm would date to around 1200 AD. The extrapolated dates should be treated with caution as they assume there has been no change in accumulation rate, an assumption likely to be false.

Table 6 210Pb chronology of the Mill Lough core LMIL1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2007	0				
1	0.0739	2006	1	2	0.054	0.662	12.5
2	0.1556	2004	3	2	0.0524	0.607	10.9
3	0.2373	2003	4	2	0.0508	0.551	9.4
4	0.3311	2001	6	2	0.0493	0.509	9.1
5	0.4371	1998	9	2	0.0477	0.479	10.1
6	0.5432	1996	11	2	0.0462	0.45	11.1
7	0.6492	1994	13	2	0.0446	0.42	12.1
8	0.7584	1991	16	2	0.0413	0.378	12.8
9	0.8708	1988	19	2	0.0361	0.322	13.1
10	0.9847	1985	22	2	0.0317	0.276	13
11	1.1	1981	26	2	0.0281	0.238	12.5
12	1.2194	1977	30	3	0.0255	0.21	13.3
13	1.3429	1972	35	3	0.0239	0.191	15.4
14	1.4704	1967	40	4	0.0246	0.185	17.9
15	1.602	1961	46	5	0.0277	0.193	20.9
16	1.7475	1957	50	5	0.0312	0.204	24.2
17	1.9069	1952	55	6	0.0352	0.218	27.9
18	2.0663	1947	60	7	0.0391	0.232	31.7
19	2.2384	1942	65	8	0.04	0.227	34.8
20	2.4232	1938	69	9	0.0379	0.202	37.2
21	2.6079	1933	74	10	0.0357	0.178	39.6
22	2.8117	1926	81	11	0.0331	0.158	43
23	3.0346	1918	89	13	0.0301	0.142	47.2
24	3.2575	1910	97	14	0.027	0.126	51.5
25	3.4803	1902	105	15	0.024	0.11	55.7
26	3.7032	1893	114	16	0.0209	0.094	60

LMIL1 biological data

Figures 19, 20 and 21 show the macrofossil, cladoceran and diatom stratigraphies respectively for the core from Mill Lough. The constrained clustering of the different biological groups was in relatively good agreement with a change in all the groups around 50 cm in the core. There was a further zone in both the cladoceran and diatom profiles with similar timing towards the top of the core.

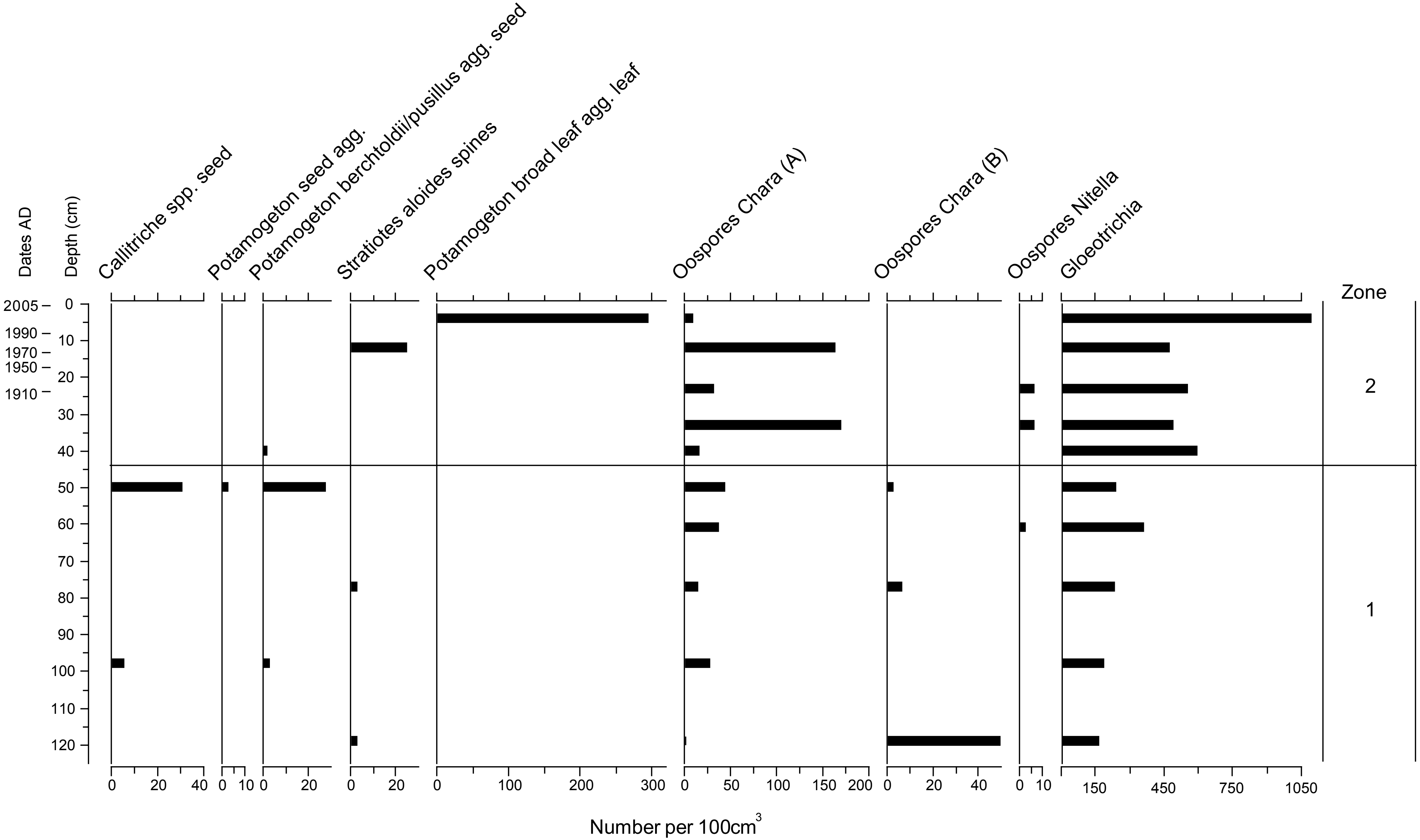
LMIL1 plant macrofossils

Given the richness of the flora of Mill Lough the abundance and diversity of sedimentary remains LMIL1 was low.

Zone 1 (*120-80 cm*)

The lower part of this section of the core contained the remains of a number of submerged species including: *Chara* type A and B, *Callitriche spp.*, *Potamogeton berchtoldii/pusillus* agg. and *Gleotrichia-type* agg. The maximum abundance of *Chara* type B was found at the base of the core and was only sporadically present for the rest of the zone. *Chara* A was present throughout the zone and increased in abundance up to *c.* 50 oospores per 100 cm^3 at the top of zone 1. *Stratiotes aloides* spines were also found at the base of the zone albeit in very low numbers

Figure 19 Summary stratigraphy for selected plant macrofossils LMIL1



Zone 2 (40-0 cm)
Zone 2 was marked by the decline and disappearance of *Callitriche* spp. and the seeds of *Potamogeton* species. *Chara* type A increased markedly in zone 1, as did the remains of the colonial algae *Gleotrichia*. *Nitella* spp oospores also occurred then disappeared in the centre of zone 2, *Stratiotes aloides* spines were present in a single sample. The uppermost sample contained plentiful remains of broad-leaved *Potamogeton* species, of which there are many species in Mill Lough currently.

LMIL1 cladoceran stratigraphy

Zone 1 (120-55 cm)
The base of the sequence had the highest diversity of benthic cladocerans, with many plant associated/benthic species, such as *Pleuroxus uncinatus, Monospilus dispar*, *Phrixura rostrata* and *Leydigia leydigii* occurring albeit in low relative abundance. Towards the top of zone 1 *B. coregoni* increased its relative abundance to around 20% at the top of the zone and *Daphnia* ephippia appeared in the record.

Zone 2 (55-10 cm)
The abundance and diversity of benthic species declined above 50cm depth. *Alona guttata/rectangula* and *Chydorus sphaericus* were the dominant the benthic species within the assemblage at this time. There was a step change in the composition of pelagic cladocerans *B. coregoni* relative abundance fell sharply to be replaced by *B. longirostris* as the dominant species (40%). The relative abundance of some benthic cladocerans, such as the plant-associated *Graptoleberis testudinaria*, *Alonella exigua* and *Eurycercus lamellatus*, increased towards the top of zones 2, as did *Daphnia hyalina* agg. ephippia which were present in relatively low numbers in the lower part of the zone but increased dramatically towards the top.

Zone 3 (30-0 cm)
There was a single sample in zone 3 which was characterised by the dramatic decline in *Daphnia* ephippia and *B. longirostris* abundance, with a slight increase in *B. coregoni*. *Chydorus sphaericus* increased in abundance in the top sample and *G. testudinaria* maintained a significant population.

LMIL1 diatom stratigraphy

Zone 1 (144-55 cm)
Zone 1 was dominated by the small benthic taxon *Staurosirella pinnata* (~40%). *Pseudostaurosira brevistriata*, *Nitzschia fonticola* and *Amphora pediculus* occurred alongside at lower relative abundances. *Navicula modica*, *Fragilaria robusta* occurred exclusively in this zone. The taxa recorded in this zone are predominantly periphytic and most are associated with the benthos, suggesting clear water conditions with light penetration to the sediment surface. PCA axis 1 scores were highest in this zone.

Zone 2 (55-7 cm)
Zone 2 recorded the appearance of a number of planktonic taxa including *Stephanodiscus parvus, Cyclotella radiosa, Asterionella formosa, Cyclostephanos tholiformis* and *Aulacoseira granulata*. This zone also saw the appearance of the epiphytic taxa *Cocconeis placentula* and to a lesser extent *Achnanthidium minutissimum*. Zone 2 also saw the continued presence of *S. pinnata*, but at considerably lower relative abundances (<10%). The abundance of *P. brevistriata* was also reduced, but *A. pediculus* continued to occur at similar abundances to those seen in zone 1.

Figure 20 Summary stratigraphy for cladocerans in LMIL1

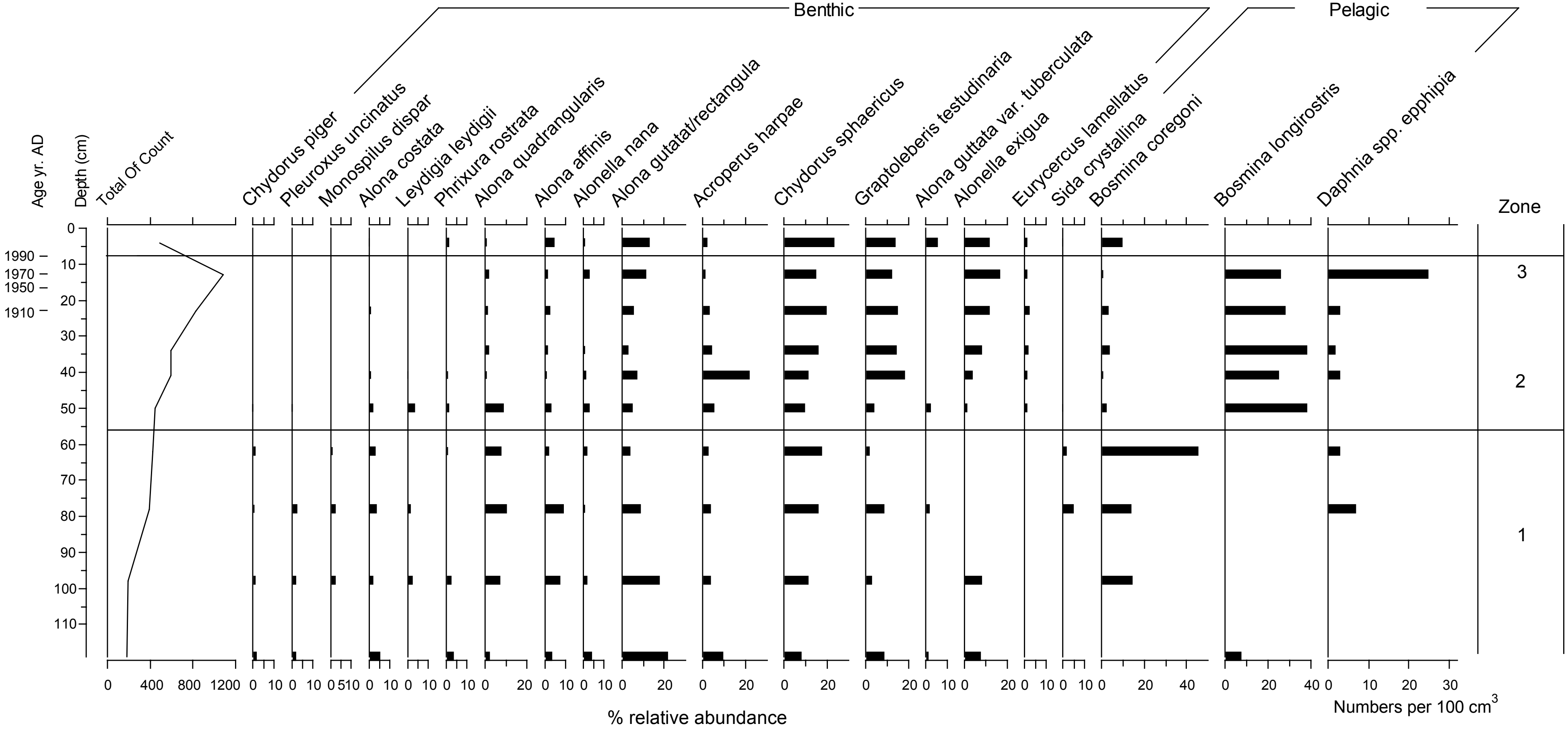
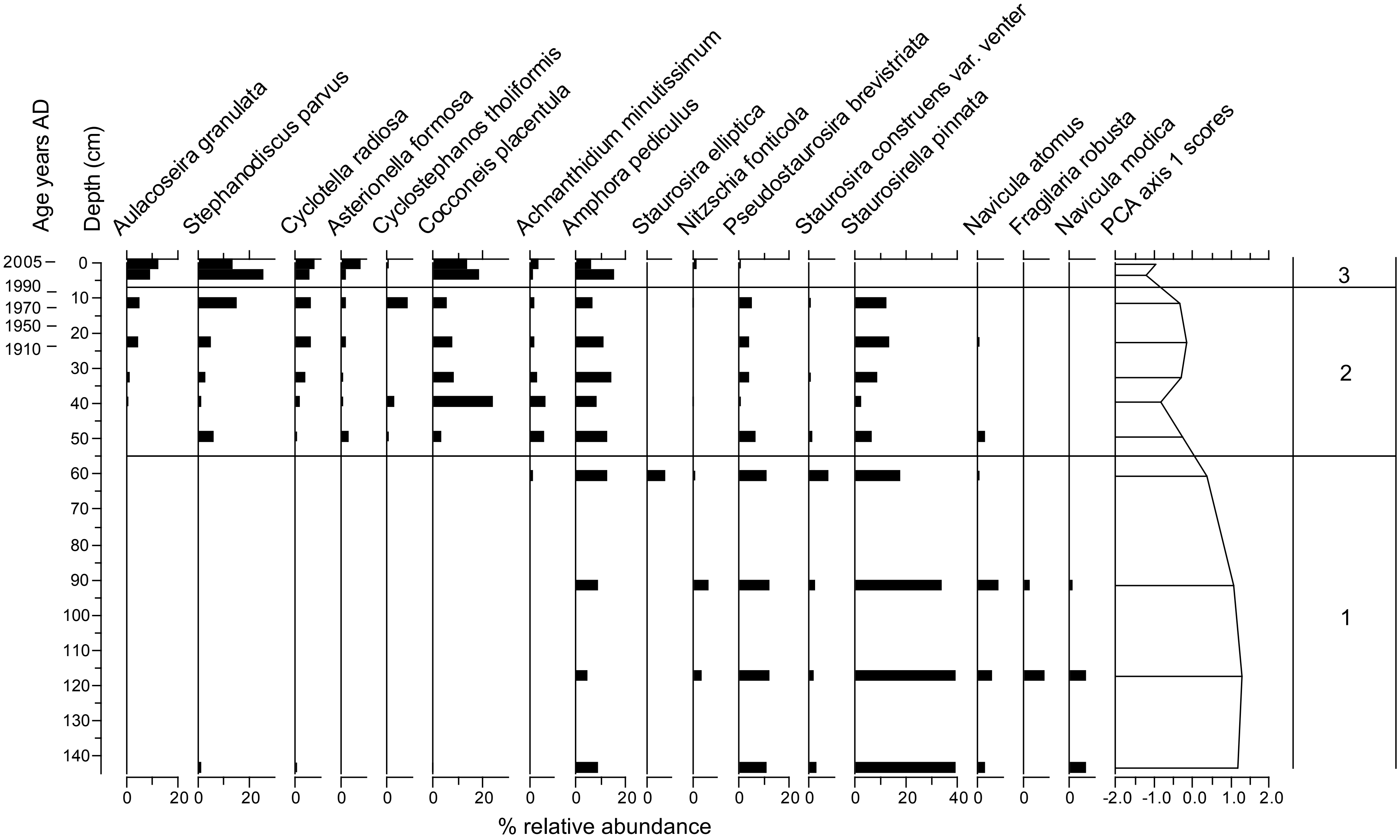


Figure 21 Summary stratigraphy for sub-fossil diatoms from LMIL1



Zone 3 (7-0 cm)

Zone 3 saw the decline of taxa associated with the benthos (in particular *S. pinnata* and *P. brevistriata*), alongside an increased abundance of diatom plankton (in particular *A. granulata* and *S. parvus*) and moderate abundances of the epiphytes *C. placentula* and *A. pediculus*, suggesting a decrease in light penetration to the sediment surface.

LMIL1 Interpretation

Given the quality and importance of Mill Lough in conservation terms it is unfortunate that the plant remains in the core were not more numerous. The different biological groups do, however, provide some insights into changes in the ecological structure and function of the site over the past, at least, 800 years. One point of interest is the recording of *Stratiotes aloides* deep in the core. The native status of this species has the subject of some debate (Forbes 2000). Spines of *S. aloides* were recorded towards the base of the core, if the accumulation rates from the ^{210}Pb dating are extrapolated then, then it would suggest that *S. aloides* was present in Mill Lough around 1200 AD. The extrapolation of accumulation rates is based on the assumption that accumulation rates have not greatly changed, which is in all probability false. It is, however, relatively unlikely that the accumulation rates were much higher in the past, and thus the date of 1200 AD is probably a conservative estimate. That is the sediments where *S. aloides* spines were found are at least 800 years old, perhaps older.

Table 7 Contemporary aquatic macrophyte community composition for Mill Lough

Submerged and floating vegetation	% occurrence 2006 (n=97)*	DAFOR 1988 (NILS)
Chara contraria	16	?
Chara curta	12	?
Chara rudis	1	?
Chara virgata	48	+
Elodea canadensis	71	A
Fontinalis antipyretica	38	R
Lemna minor	2	O
Lemna trisulca	76	A
Littorella uniflora	+	F
Myriophyllum spicatum		R
Nitella flexilis agg.	3	?
Nuphar lutea	4	F
Nymphaea alba	+	R
Potamogeton alpinus		O
Potamogeton berchtoldii	14	R
Potamogeton filiformis	4	D
Potamogeton gramineus	6	
Potamogeton lucens	3	F
Potamogeton perfoliatus	13	F
Potamogeton praelongus	7	O
Potamogeton x nitens	2	A
Potamogeton x angustifolius	7	

* Based on presence / absence data from all vegetated plots in the wader and boat based surveys
A "+" denotes the presence of a species, but which was not recorded within the survey transects
A "?" is given where identification to species level was not achieved in the 1988 survey data.

There is a large disparity between the surface sediment assemblages and the most recent contemporary plant survey (Table 7; Goldsmith *et al.* 2008), where the majority of species currently in the lake were not recorded in the surface sediments. Whilst this is disappointing in terms of gaining information on the past flora it is not that surprising as it is fairly well established that *Potamogeton* species leave relatively few remains and are under-represented in the fossil record (Davis 1985). Whilst there were abundant leaf remains of the broad-leaved *Potamogeton* species in the surface sediments their absence at lower levels is likely more attributable to a lack of preservation than the absence of broad-leaved *Potamogeton* species in the past. Other more common species, such as *L. uniflora* and *Elodea canadensis* do not leave macro-remains. Other factors contributing to the lack of remains may be the spatial patchiness of sub-fossils which can make certain areas of lake less appropriate for sediment work (Zhao *et al*. 2006).

Notwithstanding the relative lack of plant macrofossils it is still possible to infer past changes in ecosystem structure and function at Mill Lough. There appears to have been some alteration in both ecosystem structure and function over the past 800 years. The macrofossil profile suggests an increase in the abundance of *Chara* spp in the upper zone of the core, with perhaps a decline in the last 20 years. It would not be possible to make this assertion of contemporary decline based on the macrofossil record alone, however both the diatom and cladoceran profiles indicate some eutrophication induced change in the last 20 years with increases in the abundance of planktonic taxa. For the diatom assemblage there was an increase in both spring and summer blooming diatom plankton from around 55 cm with a further increase in relative abundance in the last 20 years. The cladoceran concurred with this indicating that the eutrophication induced promotion of planktonic primary production was initiated at around 55 cm with the increase in planktonic taxa *B. longirostris* and some *D. hyalina* which are symptomatic of the early stages of eutrophication. Despite these signs of eutrophication induced changes to the system the cladoceran assemblage does not indicate a decline in macrophyte abundance as the number of epiphytic cladoceran species , e.g. *G. testudinaria, E. lamellatus* are numerous in the top sample. This is in good agreement with contemporary surveys and suggests that perhaps both planktonic and macrophyte, or perhaps epiphyte production has increased at Mill Lough.

The radiometric dating also indicated an increase in accumulation rates over, in particular, the last 20 years. This tallies well with an increase in planktonic production indicated by both diatoms and cladocerans. The agreement of all the techniques applied here suggests the site has undergone significant alteration and presents a very strong case for classifying the site as ‘at risk’ and this agree with the most recent assessment of condition (Goldsmith *et al*. 2008).

Killymackan

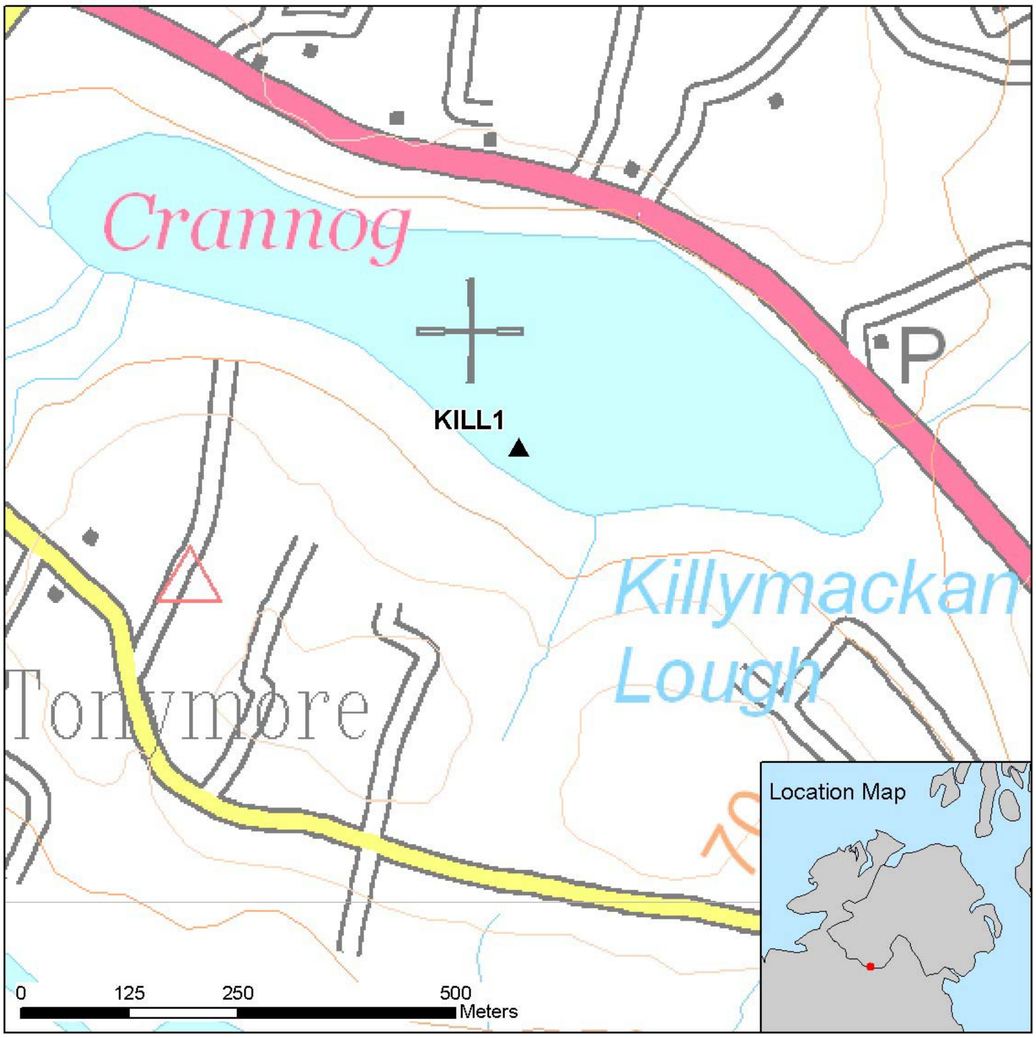
Killymackan Lough is a shallow (1.7 m), hyper-eutrophic lake with high annual mean TP (111 μgl^{-1}) which classifies it as “unfavourable” with respect to trophic status and places it within the “poor” ecological status for this lake type under the more stringent criteria set by the UK WDF TAG reports (2005). Similar results were recorded for the site in 1988 (NILS). The mean annual chlorophyll *a* concentration is just within the acceptable range for the lake type (23 μgl^{-1} has been suggested as the upper limit for Chl *a* in HA VSh lakes (Phillips 2005)). Chl *a* concentrations were particularly high in the late summer (September 2006), suggesting high algal biomass. The water was slightly turbid at the time of the macrophyte survey in July 2006 but clear in the June 2007, which concurs with the expected seasonality of algal blooms.

Killymackan Lough is directly surrounded by semi-improved pasture and much of the catchment is improved pasture. The marginal areas are a mix of reed, herbs and wet woodland to the south with *Phragmites australis, Schoenoplectus lacustris* & *E. fluviatile* dominating and *Iris pseudacorus, Juncus effusus* & *Mentha aquatica* all common. The surface area of the lake is 19.2 ha. Classified as: Annex 1 type: H3150: Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation

Killymackan Lough has a species rich submerged and floating leaved aquatic macrophyte flora both overall (17 species) and with respect to characteristic species. Nine characteristic species were recorded, including two broad-leaved *Potamogeton* species (*P. praelongus* and *P.*

perfoliatus). The characteristic species *P. crispus* was recorded in 1988, but was not observed in 2006. *Potamogeton alpinus* was dominant in 1988 ('5' on a scale of 1-5) and was not observed in 2006, along with *Eleocharis acicularis*, *Sparganium emersum, Nitella flexilis* and *Nitella mucronata*. *Ceratophyllum demersum, P. polygonifolius* and the aquatic moss *Fontinalis antipyretica* were only recorded in the 2006 survey (Goldsmith *et al*. 2008). Thus, there is evidence of recent change and the site condition assessment of the most recent survey was unfavourable.

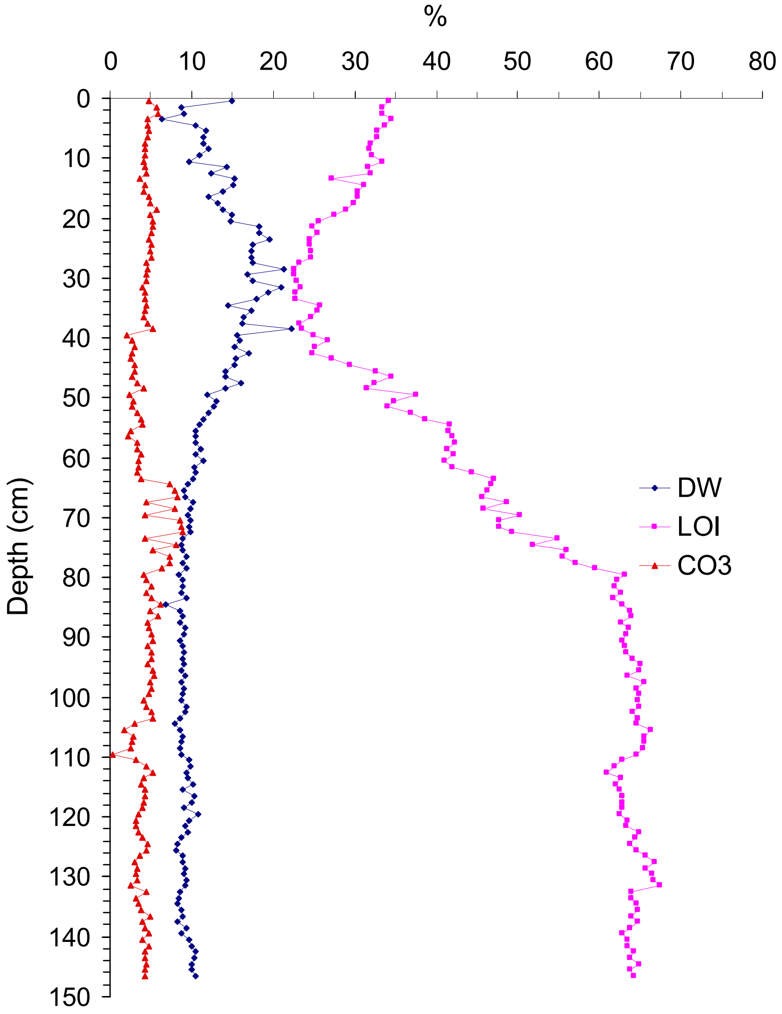
Figure 22 Map of Killymackan Lough and core site



KILL1 lithostratigraphy

The details of coring depth and location for KILL1 can be found in Table 1 and Figure 22. KILL1 had a number of distinguishing features which can be seen in Figures 23. From the base of the core from 150 cm to 80 cm, organic content, expressed as % LOI (60%), dry weight (DW) and carbonate content remained constant. From 80 cm to 40 cm there was a gradual decline in %LOI to around 25% with a concomitant rise in %DW. Above 40 cm there was a gradual increase in %LOI perhaps with a slight acceleration in the rate of increase towards the surface. Carbonate content varied little on the entire length of the core with values of around 5%.

Figure 23 KILL1 lithostratigraphy



KILL1 chronology

Lead-210 Activity

Total 210Pb activity did not appear to reach equilibrium with supporting 226Ra in this core. Unsupported 210Pb activities declined irregularly with depth, but had little net reduction from 22 cm to the bottom of the core. This makes interpreting the 210Pb profile very difficult.

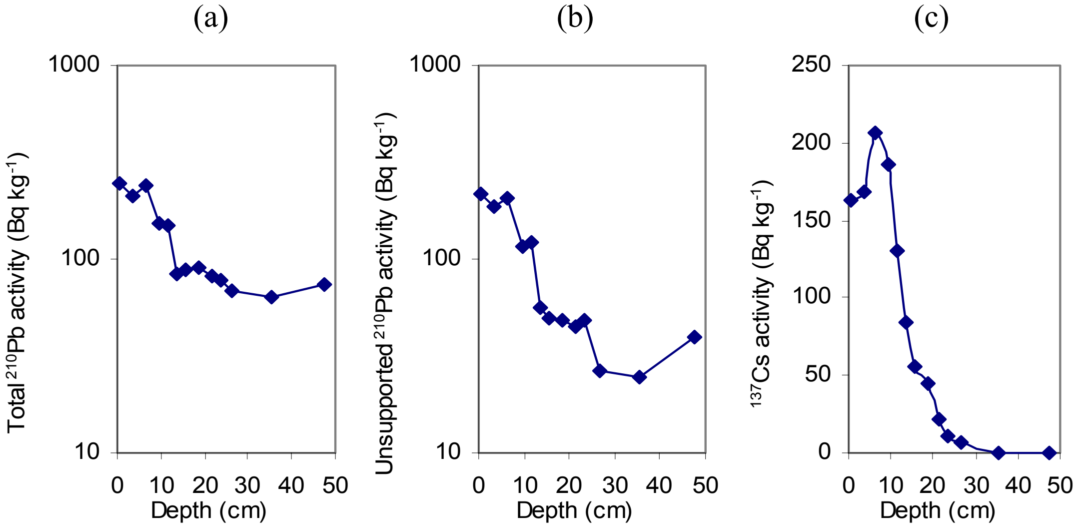
Artificial Fallout Radionuclides

The 137Cs activity versus depth showed a well-resolved peak at 6.5 cm. The relatively high concentration in the peak suggest that it dates from the 1986 Chernobyl accident.

Summary

The problems associated with 210Pb activity not reaching equilibrium with and supporting 226Ra, make using and age depth model using these data inappropriate. The lack of a second peak in the 137Cs record corresponding to the 1963 peak in atmospheric weapons testing makes this record also difficult to interpret. 137Cs may have some mobility in the sediments and thus the second 1963 peak may be obscured by a larger 1986 peak. A cautious approach to ascribing ages to depth was taken and a single date of 1986, corresponding to the peak in 137Cs activity at 6.5 cm was used for this core. Thus, it is not possible to determine whether there have been any changes in accumulation rate.

Figure 24 Fallout radionuclide concentrations in the Killymackan core KILL1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs concentrations versus depth



KILL1 biological data

The biological remains found in KILL1 revealed a number of changes in the ecology of the site over the time period represented by the core. The constrained clustering of each separate biological indicator revealed very similar zones, which accorded well with the shifts in organic content of the sediment. There was a shift at around 70 cm in the plant macrofossils (Figure 25) cladoceran (Figure 26) and diatom assemblages (Figure 27). There were subsequent changes towards the top of the core, where the complete correspondence in the timing of change was absent but the agreement on the nature of change was still good between the 3 groups.

KILL1 plant macrofossils

Zone 1 (120-65 cm)

The lower section was characterised by charophyte oospores, including small amounts of *Chara* type A, and very large numbers of *Nitella* spp reaching several 1000 per 100 cm^3. In addition there were the seeds of *Najas flexilis,* and remnant of the colonial algae *Gleotrichia*. The maximum abundances were found at 120 cm with the number of all the remains declining towards the top of the section.

Zone 2 (65-25 cm)

In zone 2 the dominant component of zone 1, *Nitella* oospores, were present in lower numbers, though still in excess of 100 per 100 cm^3 of sediment suggesting relatively abundant growths of charophytes (Zhao *et al*. 2006). A number of new taxa appeared in this zone, including three *Potamogeton* species/species aggregates, including *Potamogeton obtusifolius*, *Potamogeton* broad leaf type agg., and *Potamogeton* seed remains agg. *Isoetes lacustris* and *Callitriche* spp. appeared at 50 cm. The seeds of *Najas flexilis* were present in low numbers towards the top of the zone, whereas *Chara* type A, increased in numbers but were still present in relatively low numbers. *Stratiotes aloides* was present sporadically in this zone and *Gleotrichia* colony remains had a maximum peak at 50 cm and then declined in number.

Zone 3 (25-0 cm)

The uppermost samples displayed a fairly large change in the assemblage. *Potamogeton obtusifolius* agg, *Potamogeton* broad leaf type agg, and *Chara* type B were absent being replaced by *Potamogeton berchtoldii/pusillus* agg., leaf remains and *Potamogeton perfoliatus* seeds. *Callitriche* spp., and *Chara* type B remains increased markedly in this zone and were abundant throughout. *Nitella spp.*, *I. lacustris*, *S. aloides*, and *N. flexilis* were all present in relatively low numbers in the top zone 3.

Figure 25 Summary stratigraphy of plant remains from KILL1

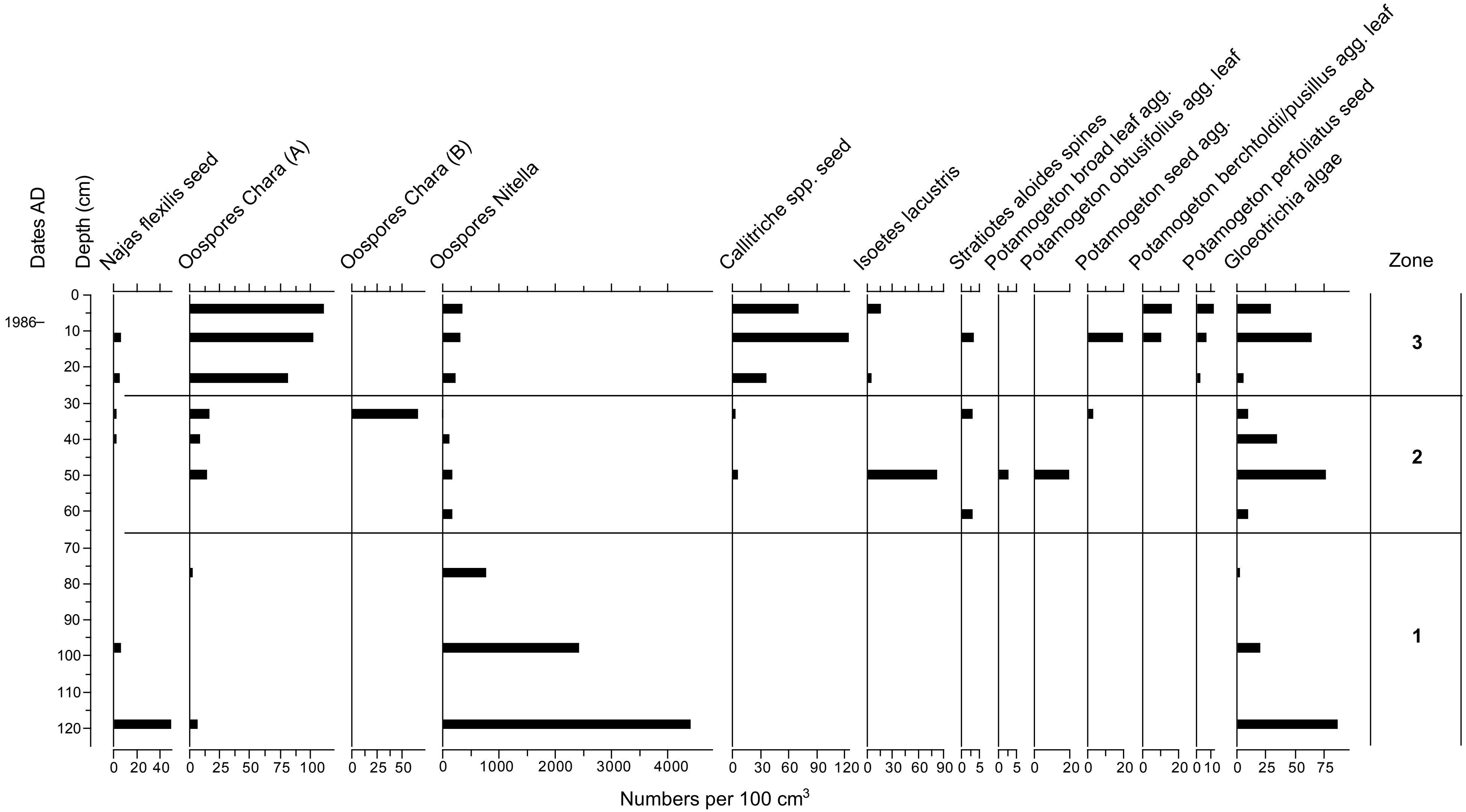
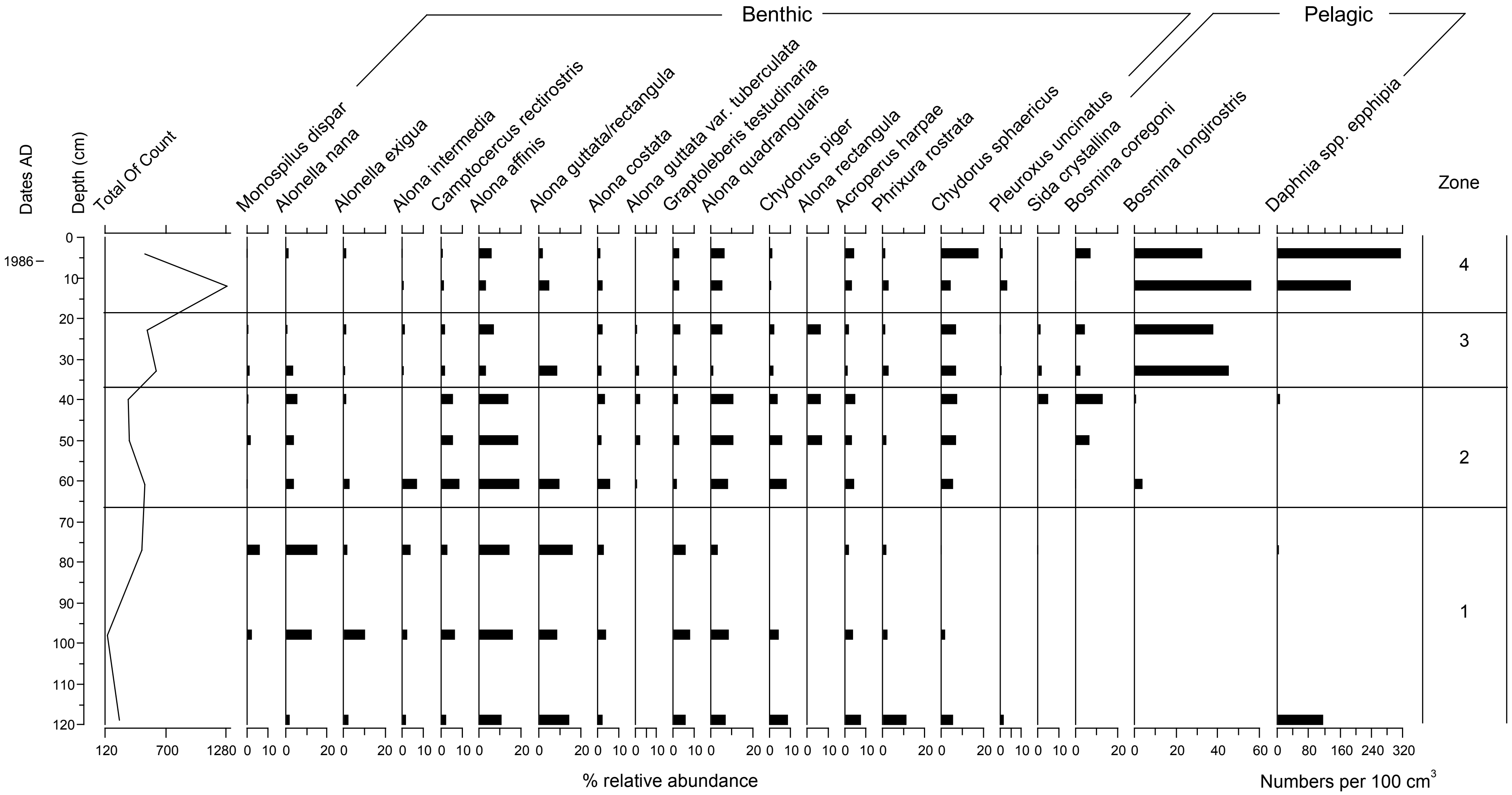


Figure 26 Summary stratigraphy of chitinous cladoceran remains from KILL1



KILL1 cladoceran stratigraphy

Zone 1 (120-65 cm)

The base of the sequence had a very high diversity of benthic cladocerans, with plant-associated species such as *Camptocercus rectirostris, G. testudinaria* and *Alonella nana*. The relatively generalist benthic species *Alona affinis* dominated the assemblage, with a relative abundance of around 10%. *Daphnia* ephippia were relatively abundant in the basal sample of the core. The absolute abundance of cladocerans was lower in the basal two samples of the core.

Zone 2 (65–34 cm)

Zone 2 saw a decline in the diversity of benthic species with an increase in the proportion of *Chydorus sphaericus* and *Alona quadrangularis. Bosmina coregoni* appeared towards the top of this section. Despite these changes the assemblage still consisted largely of benthic taxa.

Zone 3 (34–20 cm)

Zone 3 was characterised by a dramatic shift in assemblage composition to dominance of the small bodied pelagic species *B. longirostris*, which is associated with open water and relatively high chlorophyll-*a* (Davidson *et al*. 2007), and a decline in the relative abundance of benthic species. Other pelagic species, such as *Sida crystallina*, *Bosmina coregoni* were also present. There was still, however, a relatively diverse community of benthic species in zone 3, with a number of plant-associated species present.

Zone 4 (20–0 cm)

Above 20 cm there was a sharp increase in the abundance of *Daphnia* ephippia, the rest of the assemblage remained similar to zone 3, with perhaps a decline in the relative abundance of *B. longirostris*. As in zone 3, despite an increase in the numbers of pelagic taxa there were still significant numbers and diversity of plant associated species, such as *A. harpae* and *Pleuroxus uncinatus*.

KILL1 diatom stratigraphy

There was some dissolution in the diatom flora between 11 and 39 cm, samples 22.5 cm and 32.5 cm samples could not be counted due to insufficient diatoms.

Zone 1 (119 - 68.5 cm)

Zone 1 was dominated by the small benthic taxon, *Staurosirella pinnata* (30-60%). The small centric diatom, *Aulacoseira distans* was also common throughout this zone (~20%), with *Staurosira construens* var. *binodis* and *Gyrosigma accuminatum* occuring alongside at lower relative abundances. *Cocconeis placentula* var. *pseudolineata* occurred exclusively in this zone. The taxa recorded in this zone are periphytic and most are associated with the benthos, suggesting clear water conditions with light penetration to the sediment surface. PCA axis 1 scores are highest in this zone.

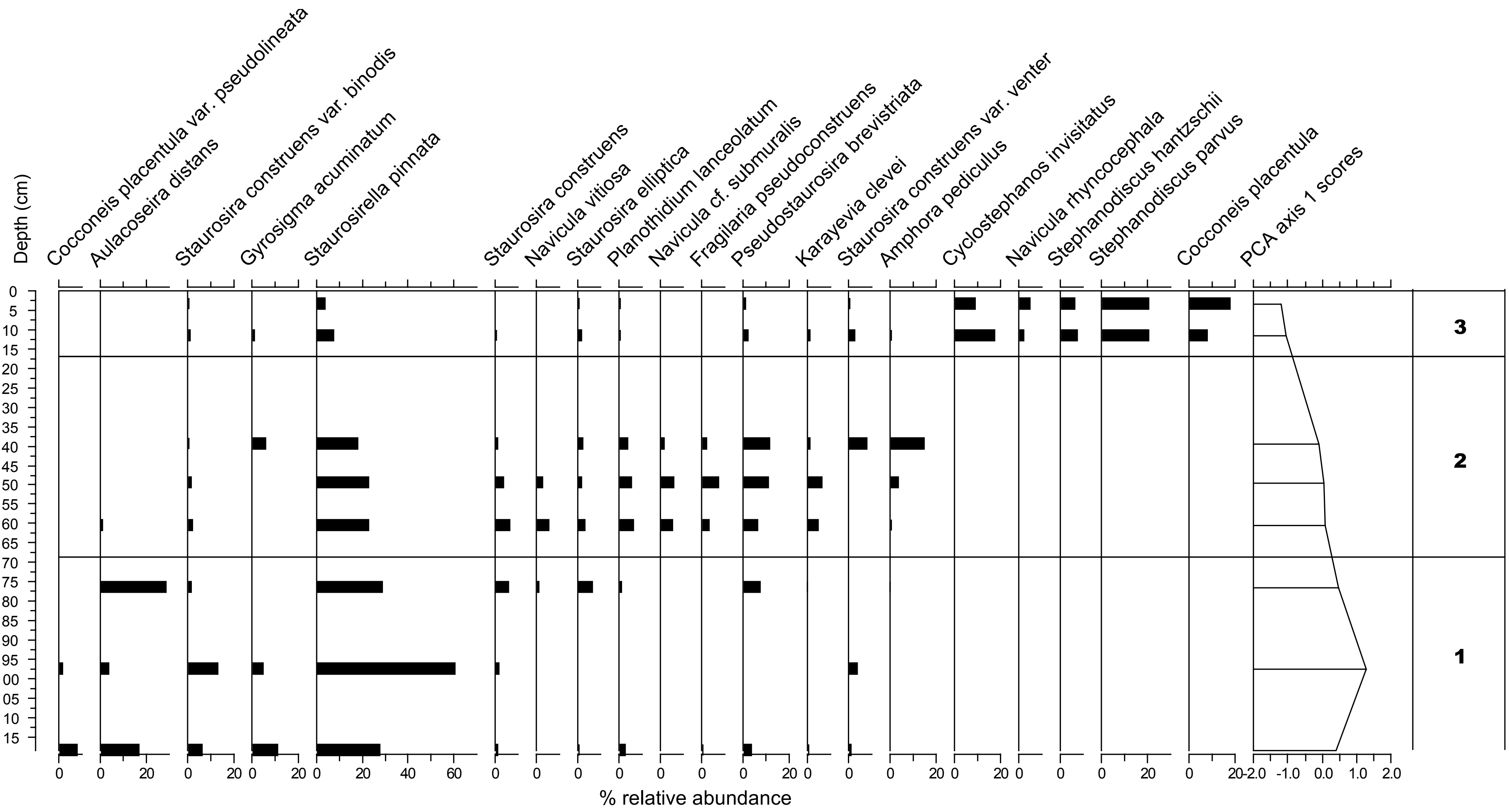
Zone 2 (68.5 - 17 cm)

Zone 2 recorded appearances or increasing relative abundances of *Amphora pediculus, Karayevia clevei, Fragilaria pseudoconstruens, Navicula cf. submuralis, Navicula vitiosa* and *Planothidium lanceolatum*. Zone 2 saw the continued presence of *S. pinnata* and *S. construens var. binodis,* but at lower relative abundances (~20% and >5% respectively). The abundance of *A. distans* also decreased significantly and this taxon disappears in Zone 2.

Zone 3 (17-0 cm)

Zone 3 saw the decline of taxa associated with the benthos (in particular *S. pinnata*) and the appearance of a moderate to high relative abundance of diatom plankton (in particular *Stephanodiscus parvus, Stephanodiscus hantzschii* and *Cyclostephanos invisitatus*). This zone also saw the appearance of the epiphyte *Cocconeis placentula* and the benthic taxon *Navicula rhyncocephala*.

Figure 27 Summary stratigraphy of sub-fossil diatoms from KILL1



KILL1 interpretation

The palaeoecological data for Killymackan Lough suggest that there have been profound changes in the ecology of the site. Furthermore, there has been a series of more recent changes which appear to threaten the biological integrity of the lough.

The data suggest that there has been nutrient enrichment of the site from a more oligo-mesotrophic lough at the base of the core. At this time *Nitella* spp. appears to have been dominant with some *Chara* and *Najas flexilis* present. The latter species is currently thought to be absent in Northern Ireland, thus any information on its past distribution is of note. The basal macrofossil assemblage suggest a relatively species poor assemblage and whilst *Nitella* spp. can be associated with relatively base poor systems, *Najas flexilis* is more associated with higher alkalinity values. The organic content of the sediments for zone 1 was very high >60%, values normally associated with peat. Furthermore, the concentration of cladocerans in the bottom 2 samples was very low. These factors might indicate that the lake, or perhaps the coring site, was subject to some degree of water level change resulting in more peaty conditions in the sediments. The diatoms at this time were benthic attached forms which indicates clear water and limited growth of algae in the plankton.

Table 8 Contemporary aquatic macrophyte community composition for Killymackan Lough.

Submerged and floating vegetation	% occurrence 2006 (n=108)*	DAFOR 1988 (NILS)
Callitriche hermaphroditica	6	R
Ceratophyllum demersum	2	
Chara virgata	31	
Eleocharis acicularis		
Elodea canadensis	71	A
Fontinalis antipyretica	9	
Lemna minor	44	F
Lemna trisulca	69	A
Myriophyllum spicatum	1	D
Nitella flexilis		+
Nitella mucronata		+
Nuphar lutea	44	D
Potamogeton alpinus		D
Potamogeton crispus		R
Potamogeton natans	1	A
Potamogeton obtusifolius	1	F
Potamogeton pectinatus	7	F
Potamogeton perfoliatus	8	O
Potamogeton polygonifolius	5	
Potamogeton praelongus	1	O
Potamogeton pusillus	48	A
Sparganium emersum		
Spirodela polyrhiza	48	

* Based on presence / absence data from all vegetated plots in the wader and boat based surveys
A "+" denotes the presence of a species, but which was not recorded within the survey transects
A "?" is given where identification to species level was not achieved in the 1988 survey data.

Above the first zone the assemblages became more species rich with the appearance of a number of species of *Potamogeton* including broad-leaved species, along with *Isoetes lacustris, Najas flexilis* and *S. aloides*. Organic content in the sediments fell in this period and the cladoceran community indicates that there was very little planktonic production, thus the system was very likely to have low chlorophyll-*a*, clear water and a diverse macrophyte community. The diatom assemblage agreed with this being dominated by benthic species, there was however an increase in the diversity of the assemblage. Above 30 cm in the core there was a shift in both the macrophyte community and the ecological function which ties in well with current observation. The sedimentary record suggests that broad-leaved *Potamogeton* species have given way to more fine leaved species, reflected in the most recent contemporary date where *P. pusillus* was dominant (Goldsmith *et al*. 2008). Diatoms did not preserve well in this phase, perhaps suggesting high pH events and raised alkalinity. Both contemporary survey and macrofossil records agree that there has been a shift to *Chara* being the more abundant than *Nitella*. The trend in the cladoceran assemblage, i.e. the increasing relative abundance of planktonic species (in particular *Daphnia*), in the uppermost section of the core suggest an increase in the proportion of primary production that is planktonic, a phenomenon characteristic of eutrophication (Vadeboncoeur *et al*. 2005). This is confirmed by the diatom assemblage, which at the top of the core shifts to the dominance of planktonic forms. These shifts suggest that the control of the algal crop at Killymackan has shifted from a situation where it is controlled from the bottom up by nutrients to a situation where grazing cladocerans are the important controlling factors. This reliance on top-down forces for the maintenance of clear water conditions, and therefore higher biodiversity, is subject to much greater risk than bottom-up limited systems decreasing the resilience of the site, placing Killymackan at risk of a further decline in ecological condition.

Upper Lough Erne Trannish

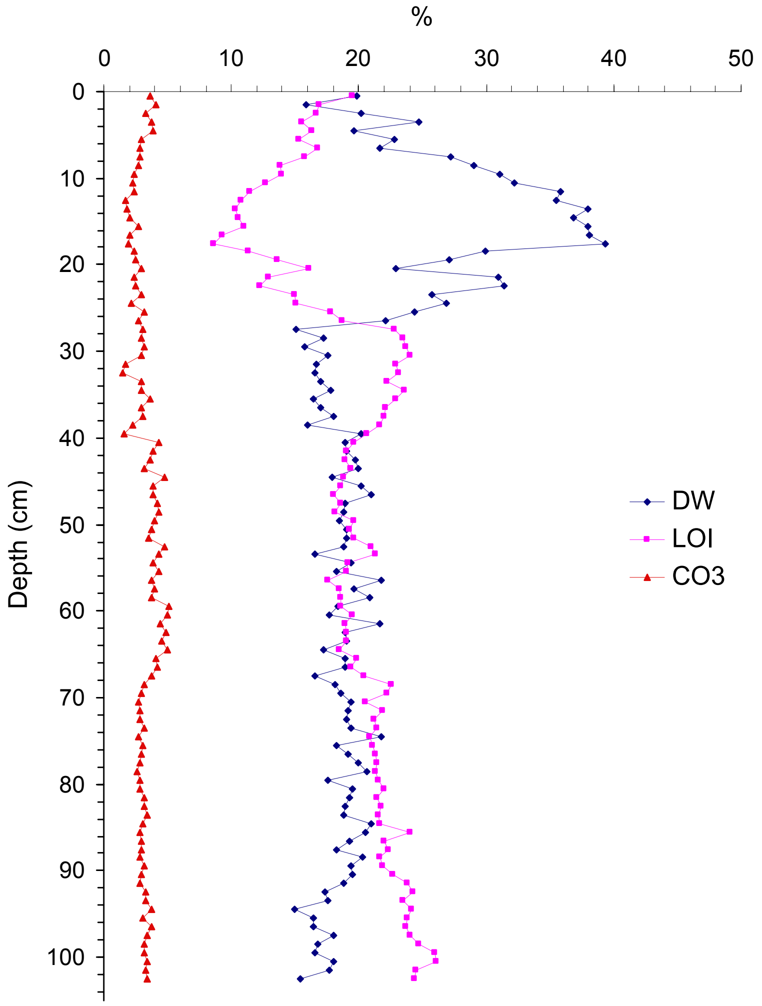
Figure 28 Map and coring location for ULET1

Upper Lough Erne (ULE) Trannish forms part of the main body of Upper Lough Erne and has a species rich submerged and floating leaved aquatic macrophyte flora both overall (23 species) and with respect to characteristic species for its water body type. In 2006, nine characteristic species were recorded, including three broad-leaved *Potamogeton* species; *Chara globularis, Lemna minor, Lemna trisulca*, *Potamogeton obtusifolius*, *Potamogeton lucens, Potamogeton lucens* x *gramineus, Potamogeton perfoliatus, Ranunculus circinatus* and *Spirodela polyrhiza*. Four other species (*P. berchtoldii, P. crispus, Stratiotes aloides* and *Utricularia vulgaris*) were recorded in 1991, but not observed in the 2006 survey, which is thought likely to be a result of the higher sampling effort employed during the earlier survey (8 days at 35 locations in 1991, compared to 3.5 days at 8 locations in 2006) (Goldsmith *et al*. 2008).

ULET1 lithostratigraphy

The details of coring depth and location for ULET1 can be found in Table 1 and Figure 28. ULET1 had a number of distinguishing features which can be seen in Figure 29 The base of the core from 110 cm to 40 cm, organic content, expressed as % LOI (60%), fell very gradually from 25% to 20% and conversely dry weight (DW) increased gradually. From 40 to 30 cm % LOI rose back to 25% and then fell to less than 10% at around 18cm, after which it rose gradually to 20% at the surface. The patterns in DW mirrored these changes. Carbonate content varied little along the length of the core.

Figure 29 Lithostratigraphy of ULET1

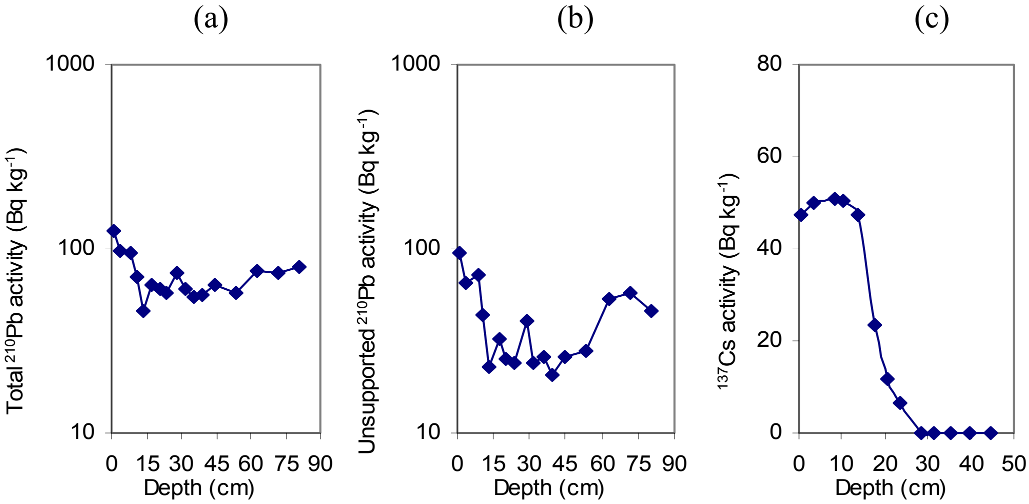


ULET1 chronology

Lead-210 Activity

Total 210Pb activity did not reach equilibrium with supporting 226Ra in this core. There is a small decline in unsupported 210Pb activities in the top 10 cm, but there is little net reduction from 10 cm to the bottom of the core (Figure 30).

Figure 30. Fallout radionuclide concentrations in the Upper Lough Erne core ULET1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs concentrations versus depth.



Artificial Fallout Radionuclides

The 137Cs activity versus depth shows a very board peak in the top 14 cm, which might suggest that mixing of the sediments has occurred, though the decline in unsupported 210Pb activities between 0 – 10 cm is contradictory to this.

Summary

The dating of this core was not successful and no dates can be ascribed to the core. This may call into question whether the core has been laid down sequentially and the biological remains found represent change through time. The nature of ULE is a shallow and relatively wind stressed water body thus it seems likely there is a relatively high degree of mixing (as suggested by the 137Cs dates.), in particular during the winter. It is, therefore that the top section of the sediments, between 1 to 3 cm, are mixed each winter so a single slice is likely to represent a mix of several years. Hence any signal reflecting biological change is likely to be smoothed in the sediment record and a dramatic shift would appear to be a less sharp change. Notwithstanding these issues the lithostratigraphic data, such as DW, LOI and carbonate indicate that the sediments were laid down chronologically and that the biological remains reflect the changing ecology of the site, unfortunately the time period represented by the core is very uncertain.

ULET1 biological data

The core presented here was taken in addition to those stipulated in the project tender and represents extra data, thus it was not possible to analyse as many levels as in the other cores. The results are very interesting demonstrating that Upper Lough Erne has undergone very profound changes in its ecology. The lack of a chronology for the core is unfortunate making it difficult to make an educated guess at the age of the core

ULET plant macrofossils

Zone 1 (60-10 cm)

The aquatic/ submerged species diversity within ULET1 was high with the lower section of zone 1 dominated by very high numbers of *Callitriche* seeds, *Najas flexilis* seeds, *Stratiotes* spines, oospores of *Chara* (A) and *Nitella* (A), *Potamogeton* broad-leaved species remains and *Isoetes lacustris* megaspores. Throughout the zone the *Callitriche* seeds, the oospores of *Chara* (A), *Potamogeton* broad leaf remains and the *Stratiotes* spines declined in abundance. However, the numbers of *Najas flexilis*, *Isoetes lacustris,* oospores of *Nitella* (A) and *Potamogeton* fine leaved species leaves remain constant and abundant throughout the zone. Remains of *Isoetes echinospora* are also present in low abundances throughout the lower section of the core and increase in abundance in the upper section of zone 1. *Nymphaeaceae trichosclereids* remains first appear at 30cm and increase in abundance towards the top of the core.

Zone 2 (10-0 cm)

Zone 2 contained only the subsurface sample, in which species diversity was low, with only a few species present including *Isoetes lacustris,* fine leaved *Potamogeton* species and numerous *Nymphaeaceae trichosclereids* remains.

ULET cladoceran stratigraphy

Zone 1 (60-22 cm)

In Zone 1, plant-associated species such as *Alonella nana*, *Graptoleberis testudinaria* and *Camptocercus rectirostris* were relatively abundant (5 - 10%). *Alona affinis* dominated the species assemblage with a relative abundance between 20 – 40%. Also present in this zone, albeit in relatively low numbers were the pelagic species *Bosmina coregoni* and *Daphnia hyalina* agg.

Zone 2 (22-0 cm)

Above 22 cm other species of *Alona* became increasingly common, along with the plant-associated species *Pleuroxus uncinatus*, *Phrixura rostrata* and *Acroperus harpae*. The small-bodied pelagic cladoceran *Bosmina longirostris* also became more abundant (20%) and the numbers of *Daphnia hyalina* agg. and *Daphnia pulex* ephippia increased. There was quite a substantial change between the top two samples with a reduction in *Daphnia* abundance at the top of the core and perhaps a slight increase in some plant associated taxa.

ULET interpretation

In the absence of a coherent chronology for ULET1 confident interpretation of the sequences is difficult. It is likely that mixing of the top layers of sediment has occurred and that propagules from satellite lakes may find their way into the system. These factors may contribute to the occurrence of *I. lacustris* in the top-most sample (though this was not the surface), when it has not been recorded in the main Lough for some time. The smoothing of the ^{137}Cs in the top 14 cm suggests that these sediments have been accumulated since 1960, and so the major changes have occurred since around the middle of the 19th century, this is, however, highly speculative.

Notwithstanding the problems of chronology the core contains some very interesting information. As in some of the other cores, *S. aloides* occurs at low levels in the core hinting at long-term residence in Ireland. In addition, it appears that *N. flexilis* was previously relatively common in the Upper Lough Erne system, the seeds being abundant in the core. What is clear is the site has undergone a shift from an oligo-mesotrophic species rich flora containing both species of *Isoetes*, *Nitella*, *Chara*, *Callitriche* and several species of *Potamogeton* to a more species poor community in which *Nymphaeaceae* are a much more important component. This shift has occurred in concert with a shift in cladoceran assemblage that suggests an increase in the proportion of planktonic production which occurred around 15 cm in the core and is very likely the result of eutrophication. The work presented here suggests that further, more high resolution work, in the main Upper Lough Erne could provide some very valuable insights into the timing and nature of change in the submerged flora of the lough. Furthermore, such studies could help determine the effects and provide a longer-term perspective on the impacts of invasive species such as the zebra mussel (*Dreissena polymorpha*).

Figure 31 Summary stratigraphy of plant remains from ULET1

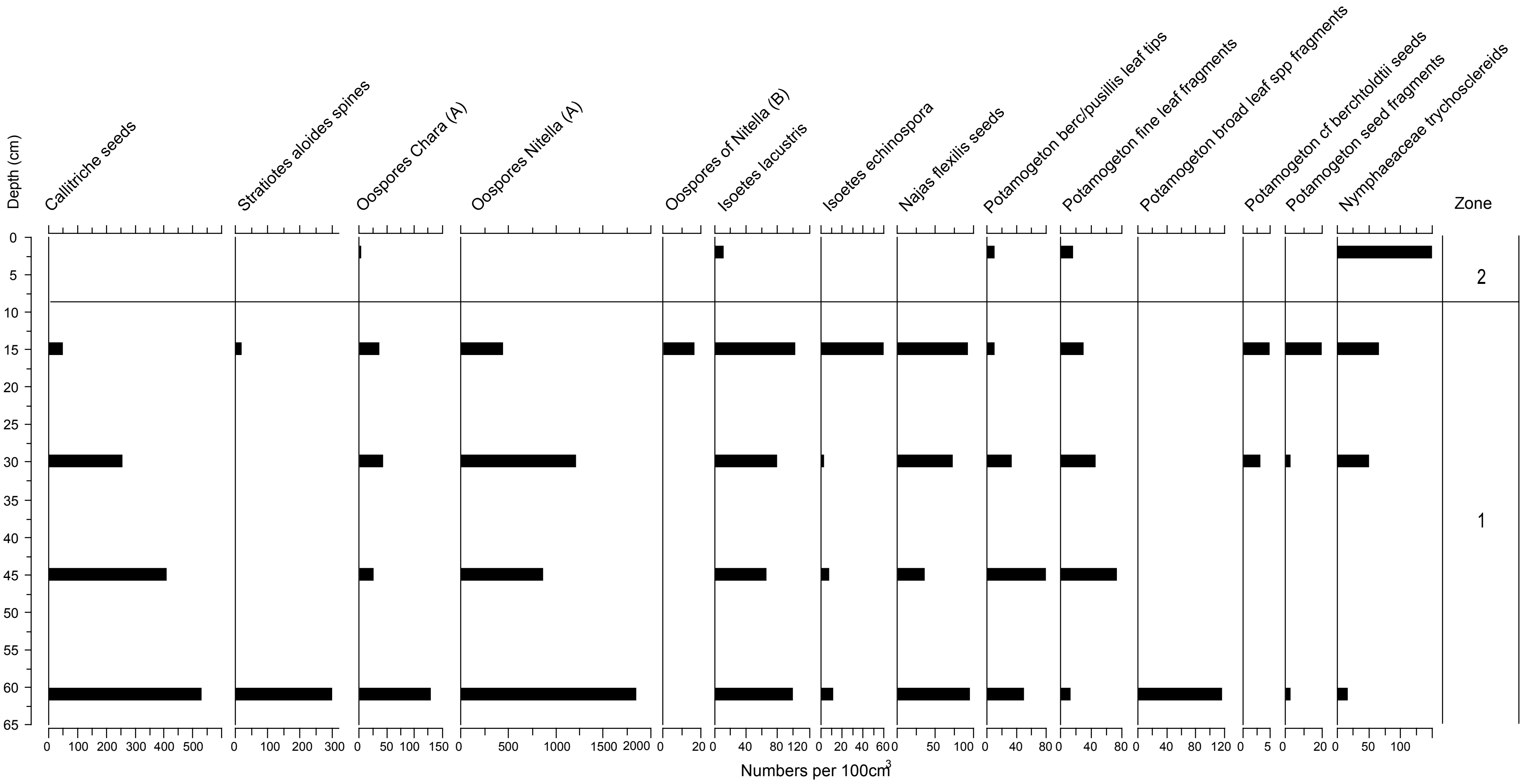
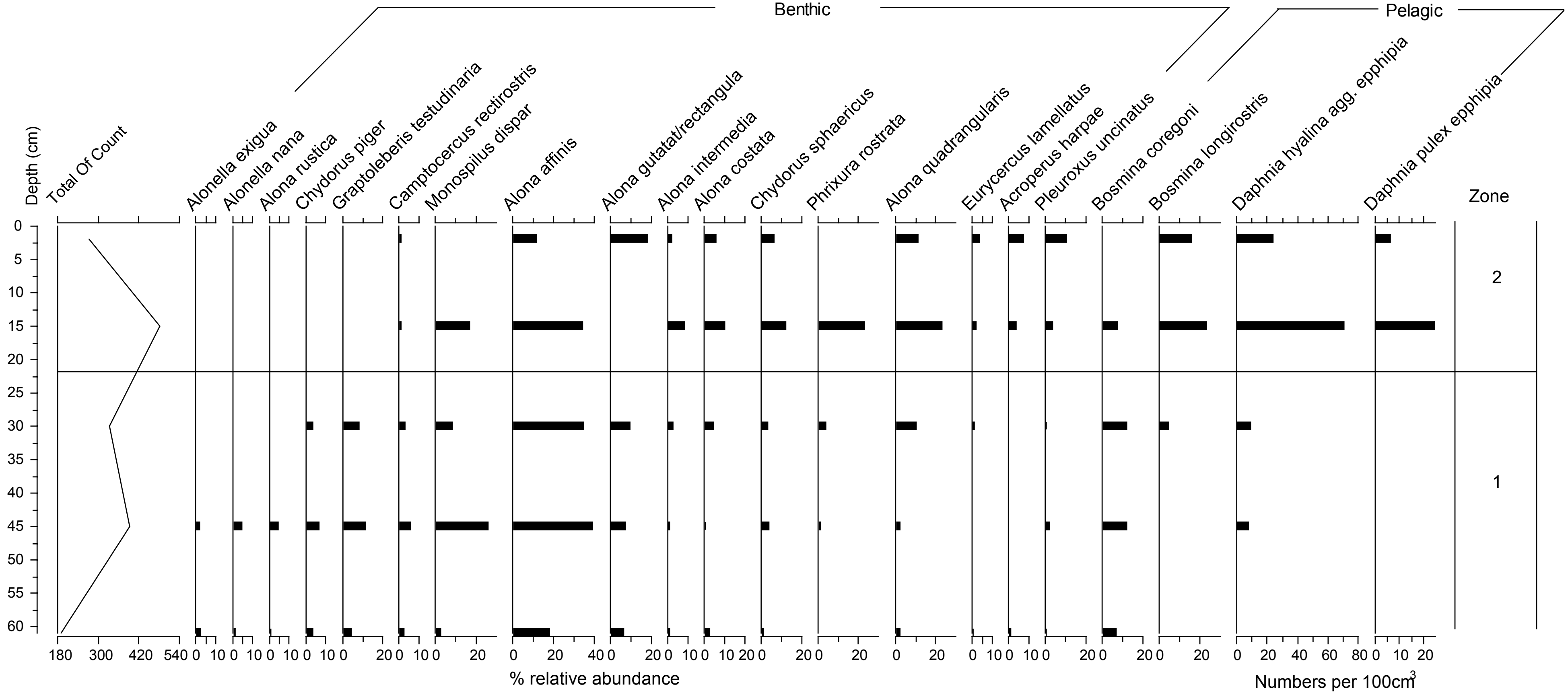


Figure 32 Summary cladoceran stratigraphy for ULET1



Magheraveely Marl Lakes

Two sites were sampled in the Magheraveely marl lakes SAC (Table 1 & Figure 1), Kilroosky and Knockballymore C were selected for study.

Kilroosky

Kilroosky Lough lies within a relatively unimproved area of wet pasture and is bordered by dense areas of *Salix* and *Betula* scrub (Figure 33). The emergent zones are varied but species rich, with *Carex rostrata, Schoenoplectus lacustris* and *Phragmites australis* dominating and *Cladium mariscus, Galium palustre* and *Mentha aquatica* also common. The surface area of the lake is 3.75 ha and is classified as: Annex 1 type: H3140: Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.

Figure 33 Map and coring location for KILR1

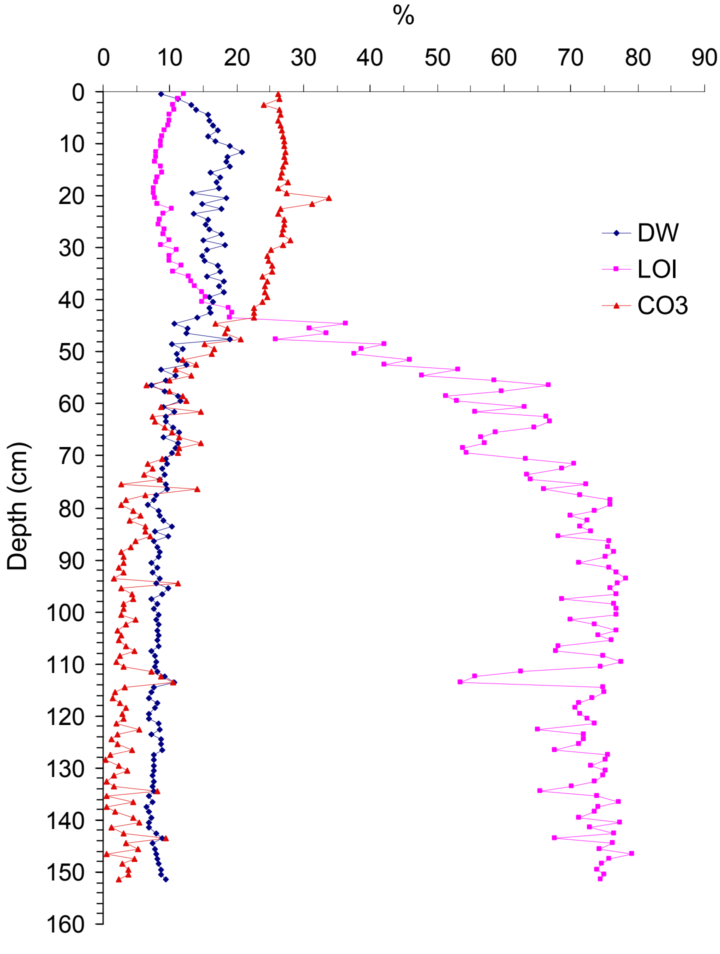
Kilroosky Lough has an exceptionally diverse charophyte assemblage with at least 6 *Chara* species present, including the nationally scarce *Chara aculeolata* and the nationally threatened *Chara rudis.* Other species recorded were *C. contraria, C. globularis, C. hispida,* and *C. virgata.* The current aquatic flora is considered favourable for this lake type. The 1989 survey of Kilroosky Lough also recorded charophytes as dominant (“5” on a 1-5 scale), but did not specify which species were present other than *C. hispida,* which was also the most frequently occurring species in the 2006 survey. The associated species *Potamogeton coloratus, Fontinalis antipyretica* and

Hippuris vulgaris were recorded in 1989 but not in 2006. *Nymphaea alba* was recorded as abundant (“4” on a 1-5 scale) in 1989 but had a very limited distribution in 2006 and was not present in the survey sections. Rare occurrences (“1” on a 1-5 scale) of *Callitriche* spp., *L. minor* and *L. trisulca* in 1989 were also not observed in 2006, though *Menyanthes trifoliata* and the associated species *Utricularia australis* were only observed in the 2006 survey. These less common taxa may simply have been overlooked as a result of the different survey methods deployed (Goldsmith *et al*. 2008).

KILR1 lithostratigraphy

The core KILR1 showed a large degree of variation along the length of the core (Figure 34). The bottom section of the core from 160 cm to 70 cm was stable, the organic content, or %LOI was >70% the % dry weight (DW) was low at 10% and carbonate <5%. From 70 cm to around 40 cm there was a gradual fall in %LOI to less than 20% at 45 cm, concurrent with this was a rise in both DW and carbonate with the latter increasing significantly to 20%. Above 45 cm the shifts were more gradual with a slight increase and decrease in carbonate and %LOI respectively.

Figure 34 KILR1 lithostratigraphy



KILR1 chronology

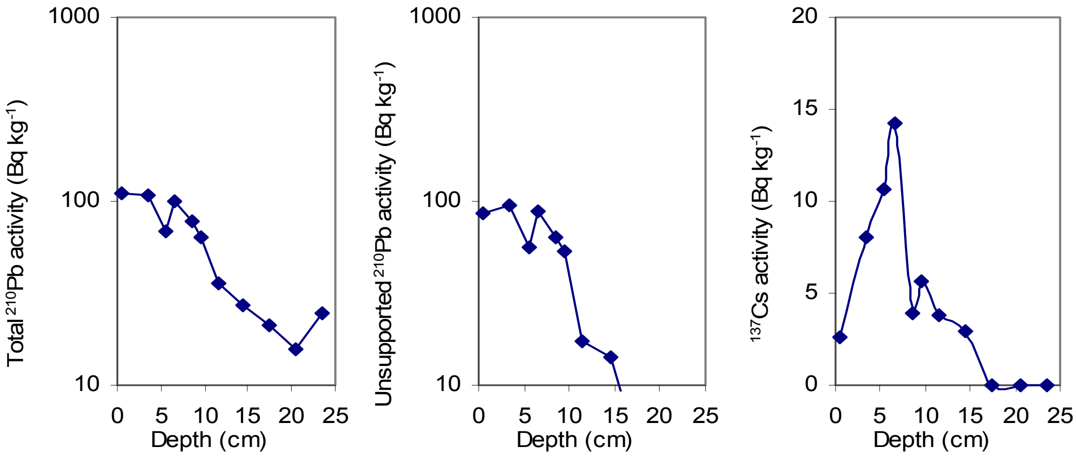
Lead-210 Activity

Equilibrium of total 210Pb activity with the supporting 226Ra occurred at c. 18 cm (Figure 35). Overall, unsupported 210Pb activities declined irregularly with depth, maximum activity occurred just below the surface sediments. The profile can be divided into two sections, there is little change in unsupported 210Pb activities in the 0 – 7 cm section, but unsupported 210Pb activity declined more or less exponentially with depth in the 7 – 18 cm section. This indicated a relatively uniform sedimentation period from 7 to 18 cm, with sedimentation rates starting to increase from 7 cm upwards to the sediment surface.

Artificial Fallout Radionuclides

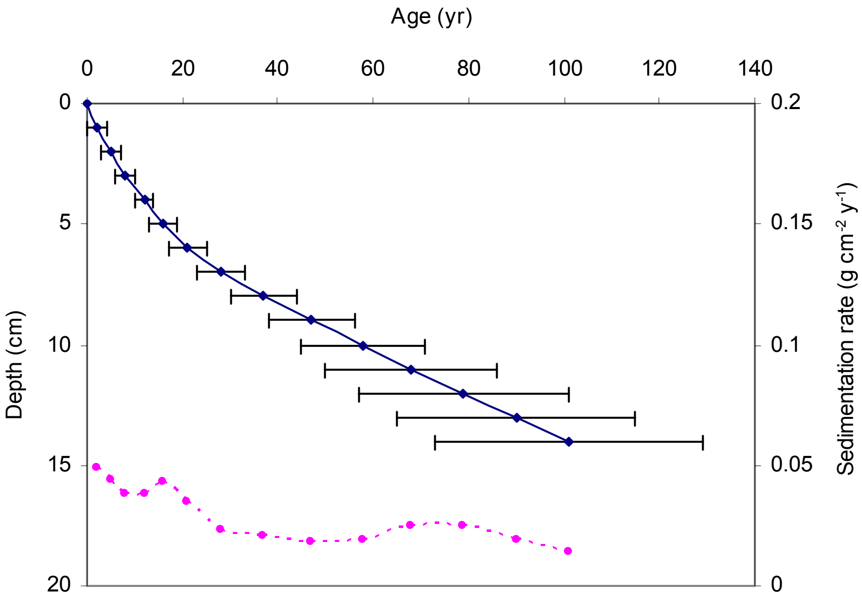
The 137Cs activity versus depth showed a well-resolved peak at c. 6.5 cm and a smaller peak at 9.5 cm (Figure 35). As the 137Cs activity was not high, it is not possible to unequivocally ascribe the 6.5 cm peak to the 1986 Chernobyl accident and the 9.5 cm peak to 1963 fallout maximum from the atmospheric testing of nuclear weapons with certainty. But as this region has been affected by the 1986 Chernobyl accident and the 1963 fallout maximum from the atmospheric testing of nuclear weapons (see the data below for the other cores in the region), the 6.5 cm peak and the 9.5 may be tentatively linked to these events.

Figure 35 Fallout radionuclide concentrations in the Kilroosky core KILR1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs concentrations versus depth



(a) (b) (c)

Figure 36 Radiometric chronology of the Kilroosky core KILR1 showing the CRS model ^{210}Pb dates and sedimentation rates.



Summary

Use of the CIC model was precluded by the non-monotonic variation in unsupported 210Pb activity. 210Pb chronologies were calculated using the CRS dating model (Appleby & Oldfield, 1978). The CRS dating model puts the 1963 layer in c. 9 cm and 1986 layer at c 6 cm, which is in relatively good agreement with the depths suggested by the 137Cs record (Figure 35). Sedimentation rates calculated using unsupported 210Pb show that sedimentation rates were relatively stable from the 1900s to the 1970s (from 14 cm to 7 cm), but have subsequently increased in the last few decades Figure 36, Table 9).The data suggest that accumulation rates have been very slow at Kilroosky, whilst some acceleration in accumulation rate is expected as a result of the fact that sediments in the upper levels are not compacted by the weight of sediment above them, the rates here exceed this natural increase.

Table 9 210Pb chronology of the Kilroosky core KILR1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2007	0				
1	0.1112	2005	2	2	0.0489	0.391	21.1
2	0.2381	2002	5	2	0.0437	0.333	21.1
3	0.365	1999	8	2	0.0385	0.274	21.1
4	0.5169	1995	12	2	0.0382	0.247	22.4
5	0.6938	1991	16	3	0.0428	0.253	24.9
6	0.8706	1986	21	4	0.035	0.192	23.6
7	1.0589	1979	28	5	0.0236	0.122	24.1
8	1.2588	1970	37	7	0.021	0.106	30.4
9	1.4587	1960	47	9	0.0182	0.09	38.5
10	1.6636	1949	58	13	0.0194	0.094	52.1
11	1.8737	1939	68	18	0.0247	0.119	69.5
12	2.0812	1928	79	22	0.0247	0.12	83.9
13	2.2862	1917	90	25	0.0195	0.095	95.4
14	2.4911	1906	101	28	0.0143	0.07	106.9

KILR1 biological data

The plant and animal macrofossils (Figures 37 & 38) and the chitinous cladoceran remains (Figure 39), display fairly distinct zonations. Plant remains were not diverse and the main shift was around 45 cm although it could be argued that the changes in assemblage started at around 70 cm which would agree with the zonation of the animal macrofossil remains. These data were included here as there were significant numbers found in core, mollusc remains, in particular, were plentiful. The animal macrofossils and cladoceran remains both had a further zone towards the top of the core at roughly the same point, corresponding to around 1900 in the animal remains and 1950 in the cladocerans.

KILR1 plant macrofossils

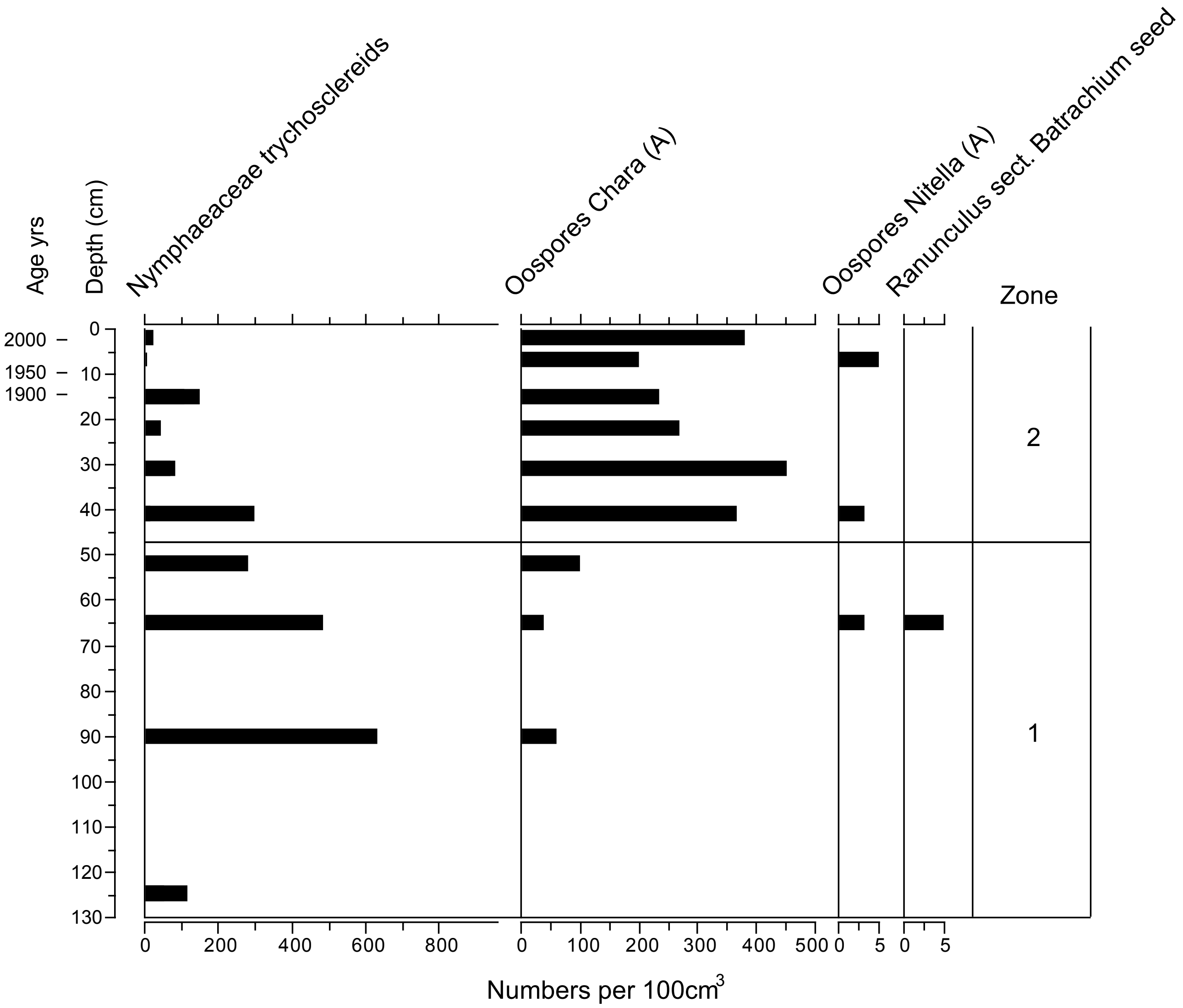
Zone 1 (125-45 cm)

Zone 1 had relatively few aquatic macrofossil remains present with limited occurrences of *Chara* oospores morphotype A in the upper section of the zone, a few *Ranunculus* subgenus *Batrachium* seed fragments and *Nitella* oospores morphotype A at 65cm. However, *Nymphaeaceae trichosclereids* remains were abundant throughout zone 1.

Zone 2 (45-0 cm)

Chara oospores morphotype A increased considerably in zone 2, reaching a maximum abundance of 453 per 100 cm^3 at 31cm, with a corresponding decrease in *Nymphaeaceae trichosclereids* remains throughout zone 2. *Nitella* oospores morphotype A were present in the samples at 7 and 41cm, but remains of *Ranunculus* subgenus *Batrachium* seed fragments were absent throughout the zone. (Numerous carbonate encrusted stems were evident in the samples throughout zone 2 and were particularly abundant at 22cm and 31cm. These findings are reflected in the higher carbonate content of the sediments in this period (Figure 34).

Figure 37 Summary plant macrofossil remains for KILR1



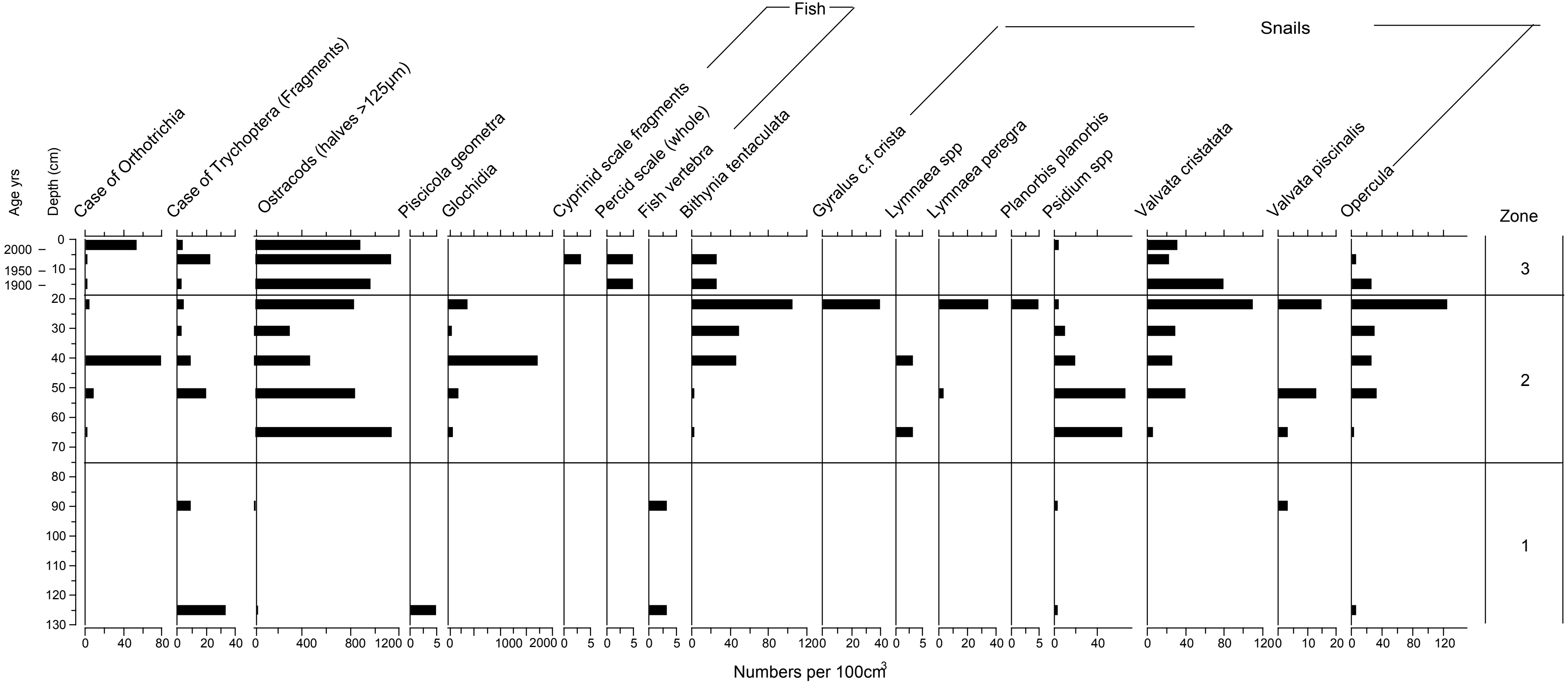
KILR1 animal macrofossils

In comparison to the macrophyte community the animal remains within KILR1 were abundant and diverse.

Zone 1 (125-75cm)

Snail abundances were limited in zone 1 with small amounts of *Pisidium* spp, in both samples, and *Valvata piscinalis* and *Opercula* present at 90 cm and 125 cm respectively. Fish vertebra and *Piscicola geometra* , a fish leech, remains in the lower section of the core confirm the presence of fish in this period of the lake's history but no fish scales were found within the lowermost section of the core. Fragments of *Trichoptera* cases reach their highest abundance in the lowermost sample but decrease towards the top of the zone.

Figure 38 Summary animal macrofossil remains for KILR1



Zone 2 (75-20cm)
Snail remains were diverse and abundant throughout zone 2. The abundance of ostracods also increased dramatically between zone 1 and zone 2 in the KILR core. Correspondingly the %LOI 950 results indicated a higher proportion of carbonate at and above ~50cm within the core. Fish remains were absent throughout zone 2. Interestingly, however, *Glochidia* remains, these are the larval stage of freshwater mussels, were found throughout zone 2 suggesting the presence of fish as a host. *Orthotrichia* and *Trichoptera* cases were also found sporadically within zone 2 with *Orthotrichia* cases reaching high abundances at 41 cm.

Zone 3 (20-0 cm)
Ostracod abundances were high throughout zone 3 whilst snail abundances and diversity were reduced compared to zone 2. Identifiable fish scale remains were evident between 20 and 0 cm and the data suggest that both Perch and Cyprinid species were present during the last 75yrs. *Orthotrichia* and *Trychoptera* cases, *Cristatella* and *Plumatella* statoblasts, and oribatid mite head were also found throughout zone 3.

KILR1 cladoceran stratigraphy

Zone 1 (120-35 cm)
The base of the sequence had a high diversity of benthic cladocerans, such as the plant-associated species, *Phrixura rostrata, Acroperus harpae, Camptocercus rectirostris* and the sediment associated *Leydigia acanthercoides*. Also present, in higher abundances towards the top of the zone were *Chydorus sphaericus* and *B. longirostris*.

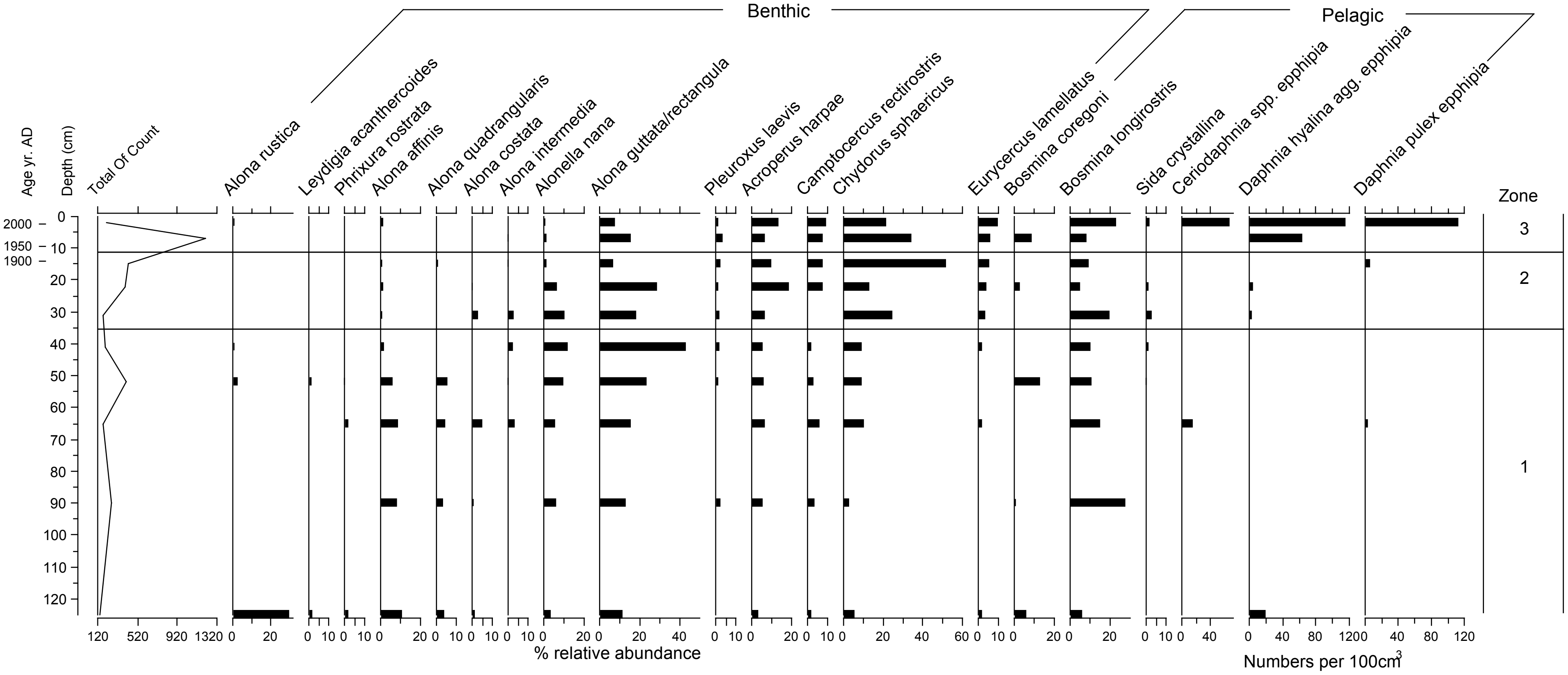
Zone 2 (35–10 cm)
Zone 2 saw a shift away from a more diverse, even community to one where fewer species were abundant, these included *Eurycercus lamellatus*, with the strongly plant associated *Acroperus harpae*, *Camptocercus rectirostris* and *Pleuroxus laevis* increasing in number. The pelagic species *B. longirostris* was consistently present at 10-20% relative abundance throughout the zone and *D. hyalina* agg. ephippia were present in low numbers in this zone.

Zone 3 (10-0 cm)
Above 10 cm there was a sharp rise in the occurrence of ephippial remains of large-bodied pelagic cladocerans *Daphnia hyalina* agg., *Daphnia pulex* and *Ceriodaphnia* spp. There was also an increase in the relative abundance of plant associated species such as *E. lamellatus, A. harpae*, *C. rectirostris* and *P. laevis*. *C. sphaericus* also increased in relative abundance

KILR1 interpretation

The combined physical, in particular the lithostratigraphy, and the biological data demonstrate the site has undergone substantial change over the time period represented by the core. Based on the extrapolation of accumulation rates in the lower section of the core, it can be speculated that the base of the core at around 120 cm correspond to about 800 AD and that the major change in macrofossil stratigraphy and %LOI, if taken at 70 cm would be placed around 1300 AD. Prior to this the sediments were very high in organic matter with levels (>70%) that suggest peat. There was a gradual change in the system to a marl system which is rich in carbonate and has an abundant and diverse *Chara* flora. It is difficult to say whether this was an entire lake change or something that occurred around the coring site. For example, a change in water depth making the area around the coring site a more permanent water body may have precipitated such a change. The cladoceran remains for zone 1 suggest a benthic system but pelagic species are also present in abundance indicating some areas of open water, which suggests whole lake change. Cladocerans, however, are more mobile than the larger plant and animal remains and thus may have travelled from more distant open water area and this could be used to argue more local core site change. The core, though taken near the lake edge was extracted from relatively deep water, it is thus very difficult to unequivocally say what the nature of the change between zones 1 and 2 were.

Figure 39 Summary cladoceran stratigraphy for KILR1

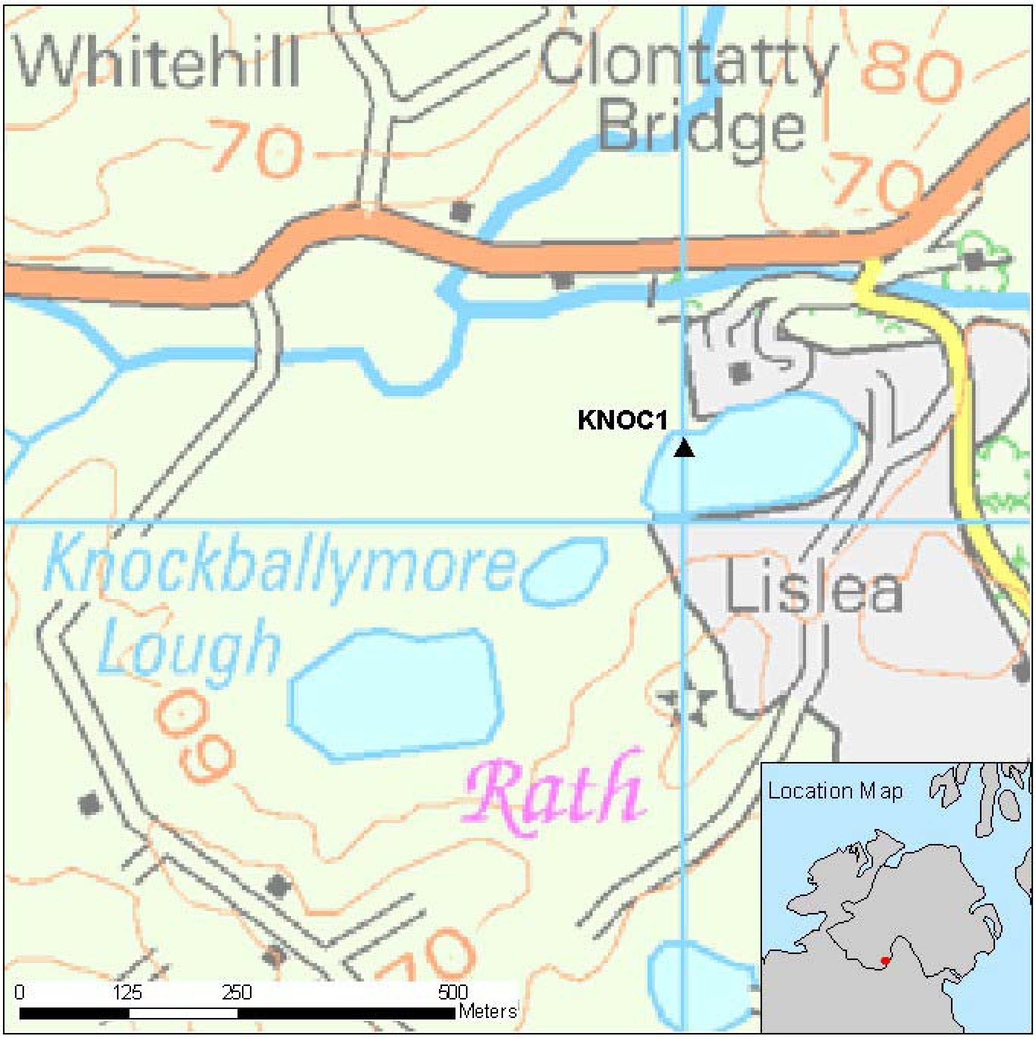


What can be asserted with some certainty is that from 70 cm in the core, speculatively since around 1300 AD, Kilroosky has been a base rich lough dominated by *Chara*, with a rich mollusc fauna. The cladoceran and the mollusc data suggest that in the last 50 years there has been an increase in the plankton of the site, as the number of planktonic species increased and mollusc density has fallen, perhaps as a result of nutrient enrichment. The cladoceran data, however, also suggest that there has been an increase in macrophyte abundance in this time period with an increase in the proportion of plant associated cladocerans. The shift in the benthic fauna, from molluscs to cladocerans, could result from nutrient enrichment but fish could also drive such a change.

Knockballymore C

Knockballymore C Lough lies within a catchment of improved and semi-improved grassland and is fringed by reed beds, dominated by *P. australis* and *S. lacustris*. *C. elata* and *T. latifolia* were present along the southern shore with *Alnus* spp. wet woodland surrounding the northern lough margins. The surface area of the lake is 2.0 ha and it Classified as: Annex 1 type: H3140: Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp (Figure 40).

Figure 40 Map of Knockballymore C and core location

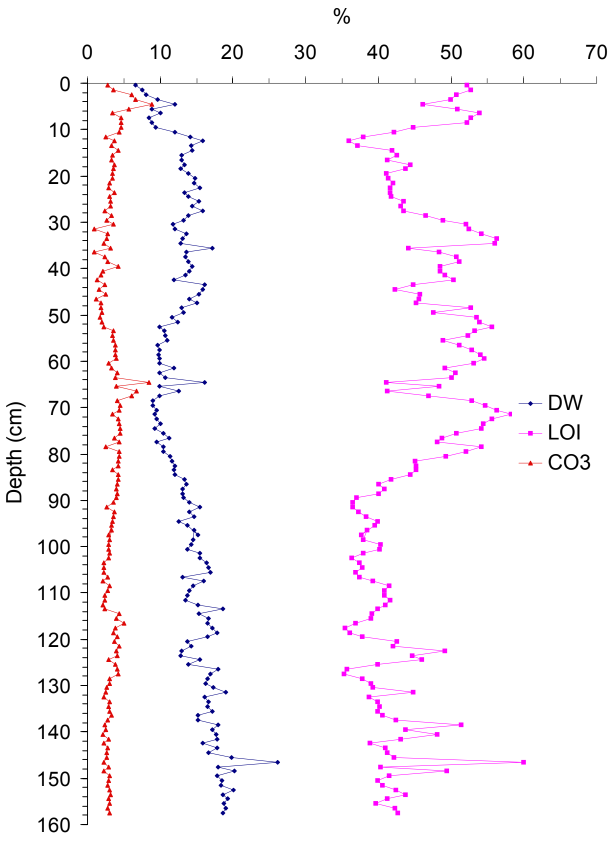


No charophytes were recorded in Knockballymore C Lough in this, or a previous survey carried out on 02/08/1988 (NILS), and it is thus classified as 'unfavourable' with respect to the flora. *Hippuris vulgaris* and *Fontinalis antipyretica* are associated with this lake type and were recorded in 1988, but not observed in the 2006 survey. Other than this, and the additional species *U. australis* and *M. trifoliata* that were only observed in 2006, the species composition between both surveys was similar (Goldsmith *et al*. 2008).

KNOC1 lithostratigraphy

There was very little large scale variation in the physical sediment properties of the core (Figure 41). Organic content varied from 40-50% along the length of the core with generally lower values below 90 cm. Surprisingly carbonate content was very low for a marl lake with all values below 10%. The patterns of dry weight generally reflected those of %LOI with higher values below 90 cm.

Figure 41 KNOC1 lithostratigraphy



KNOC1 chronology

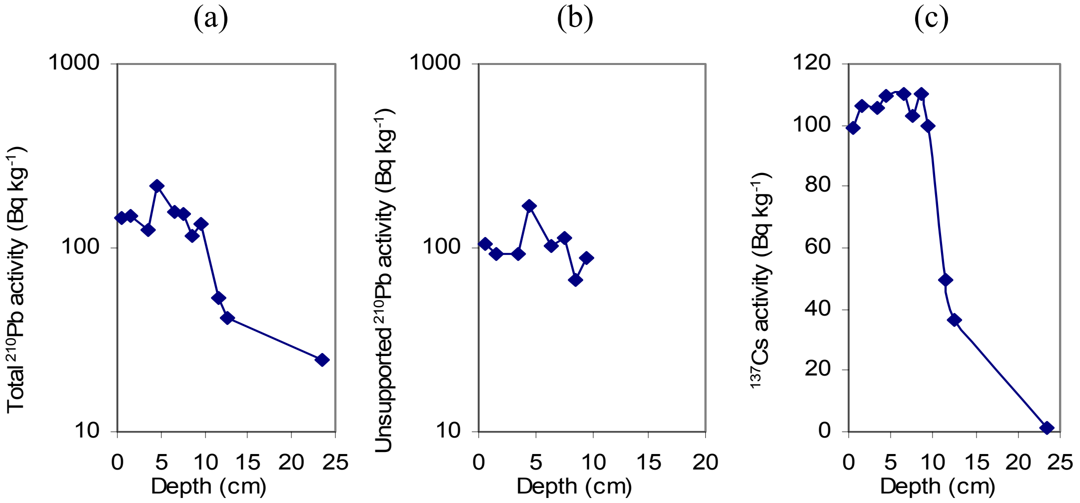
Lead-210 Activity

Total 210Pb activity reached equilibrium with the supporting 226Ra at a depth of c.11 cm of the core. Unsupported 210Pb activities had little net reduction in the top 10 cm, then sharply declined. Although there were some changes in 210Pb activity, such non-monotonic variations may imply sediment mixing in the top 10 cm.

Artificial Fallout Radionuclides

As in unsupported 210Pb activities in the core, the 137Cs activity was relatively stable in the top 10 cm, but there was a clear decline from 10 cm downwards to 26 cm. The 137Cs activity profile of the core suggests that sediments in the top 10 cm may be mixed

Figure 42 Fallout radionuclide concentrations in the Knochballymore core KNOC1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs concentrations versus depth.



Summary

The data suggest that the upper 10 cm of the core has been mixed or disturbed by some agent. The 210Pb data does not, unfortunately, provide a coherent chronology for this core and thus dates cannot be ascribed to the core.

KNOC1 biological data

KNOC1 plant macrofossils

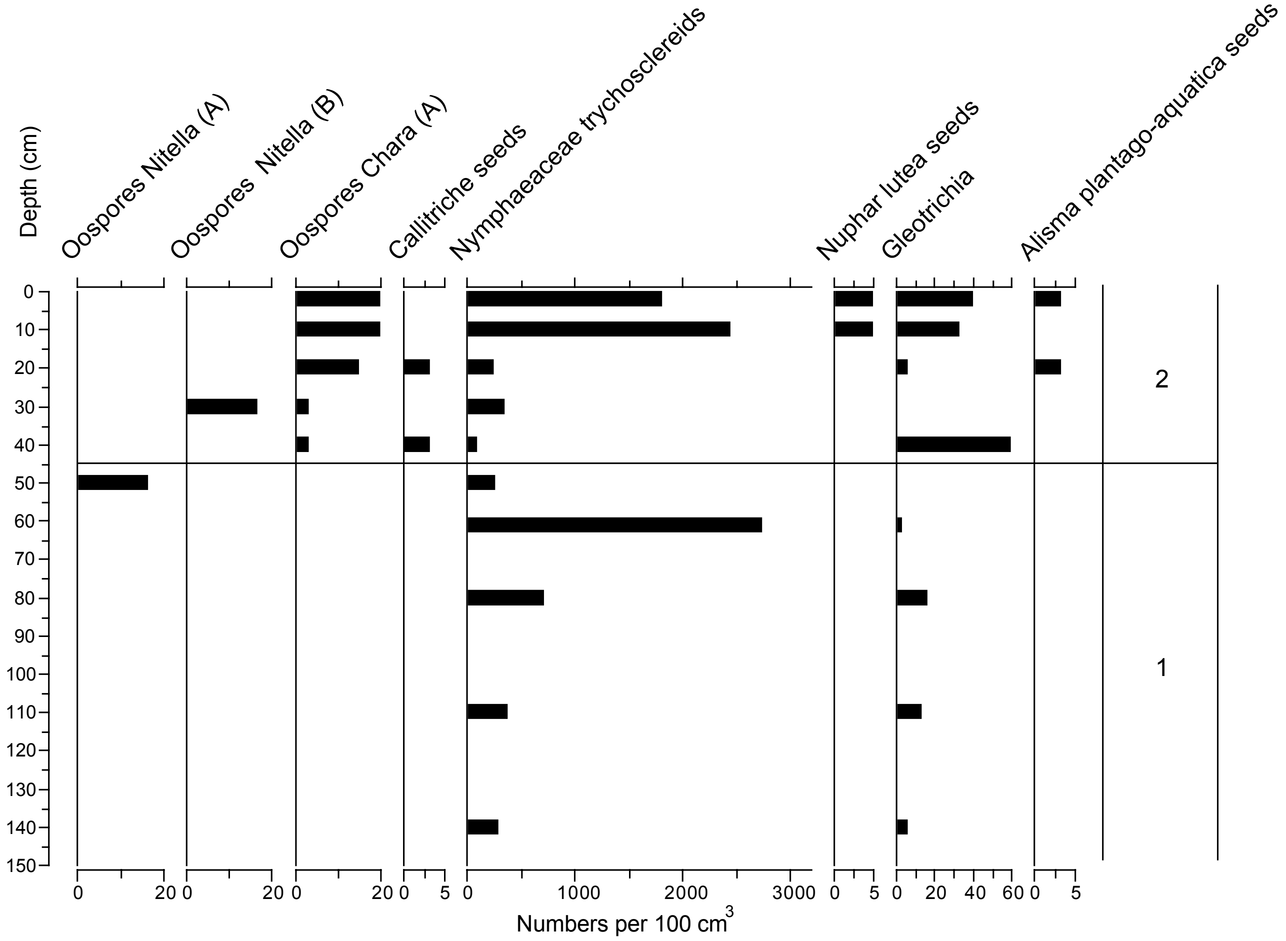
Zone 1 (140-45 cm)

Aquatic plant macrofossil remains were relatively sparse in zone 1 and particularly in the lower part of the core, with only small amounts of *Nymphaeaceae trichosclereids* and *Gleotrichia* between 140 and 80 cm. *Nymphaeaceae trichosclereids* remains reached a maximum abundance towards the top of the zone at 61cm. At 50 cm a small number of *Nitella* oospores morphotype A were found.

Zone 2 (45-0 cm)

Oospores of *Nitella* morphotype B occurred in one sample in zone 2 at 30cm. *Chara* oospores morphotype A, however, occurred throughout the zone and increased towards the surface of the core. *Callitriche* seeds were also present in the lower section of zone 2 with *Alisma plantago-aquatica* seeds also occurring, in low numbers, towards the top of the core. *Nymphaeaceae trichosclereids* remains increased in the top two core samples in which *Nuphar lutea* seeds were also present, suggesting that water lilies may have been more prevalent within the lake over the last ~100 years.

Figure 43 Summary stratigraphy of plant macrofossil remains from KNOC1



KNOC1 cladoceran stratigraphy

Zone 1 (140-90 cm)

This zone had a relatively high diversity of benthic cladocerans, such as the plant-associated species *Phrixura rostrata* and *Graptoleberis testudinaria*. *Alona guttata/rectangula* dominated the species assemblage below 80 cm. *Daphnia hyalina* agg. were present in relatively high abundance in this zone.

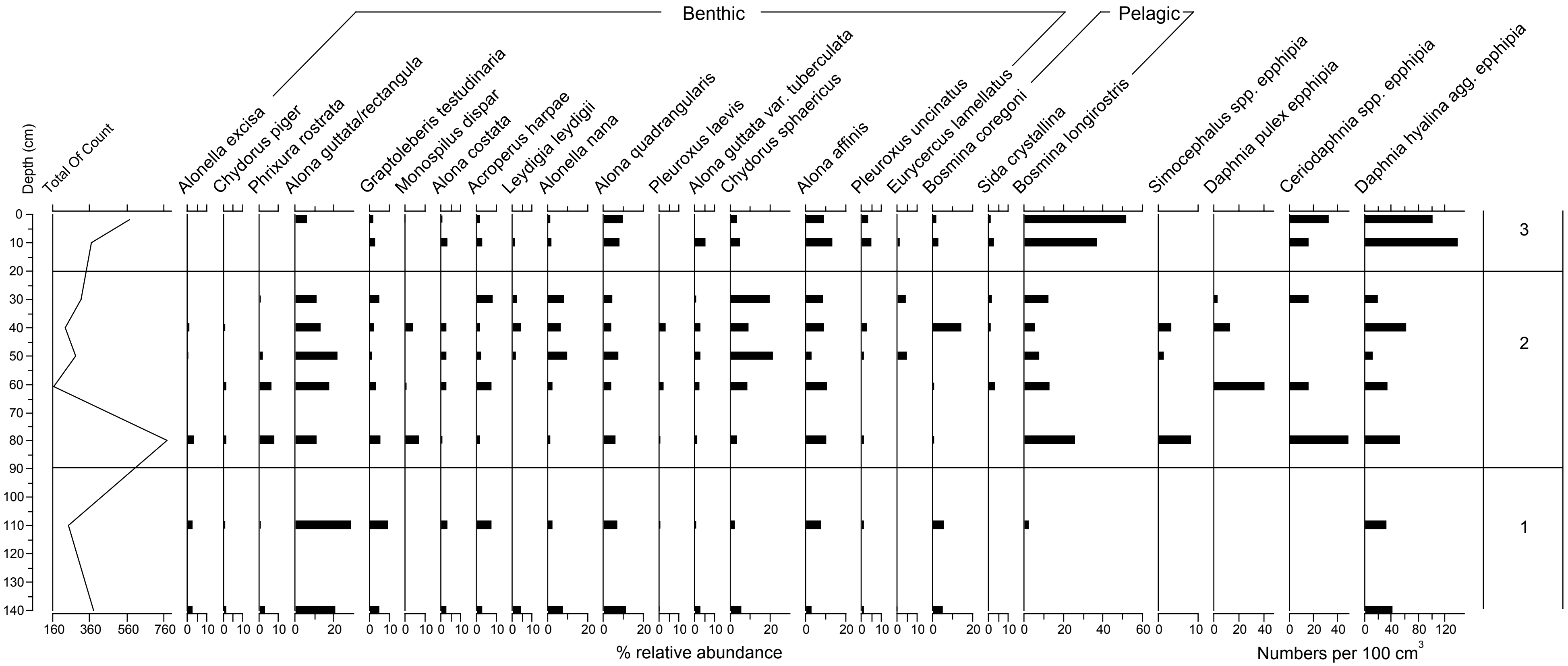
Zone 2 (90-20 cm)

The relative abundance of the small-bodied pelagic species *Bosmina longirostris* rose sharply above 10cm (40%), as did the ephippial remains of the large-bodied *Daphnia hyalina* agg., *Daphnia pulex* and *Ceriodaphnia* spp. The abundance of *C. sphaericus* also rose in this zone. The changes suggest an increase in phytoplankton production, but the continued presence of plant associated species such a *P. rostrata* and *A. harpae* suggest that submerged macrophytes were abundant.

Zone 3 (20-0 cm)

In the top zone there was a decline in the abundance of plant associated taxa and an increase in the more generalist taxa *A. affinis* and *A. quadrangularis*. The more plant associated *D. pulex* disappeared leaving only *D. hyalina* and *Ceriodaphnia* ephippia and the small bodied *B. longirostris* associate with more turbid conditions (Jeppesen *et al*. 2001) was dominant with >50% in the surface sediment.

Figure 44 Summary cladoceran stratigraphy from KNOC1



KNOC1 interpretation

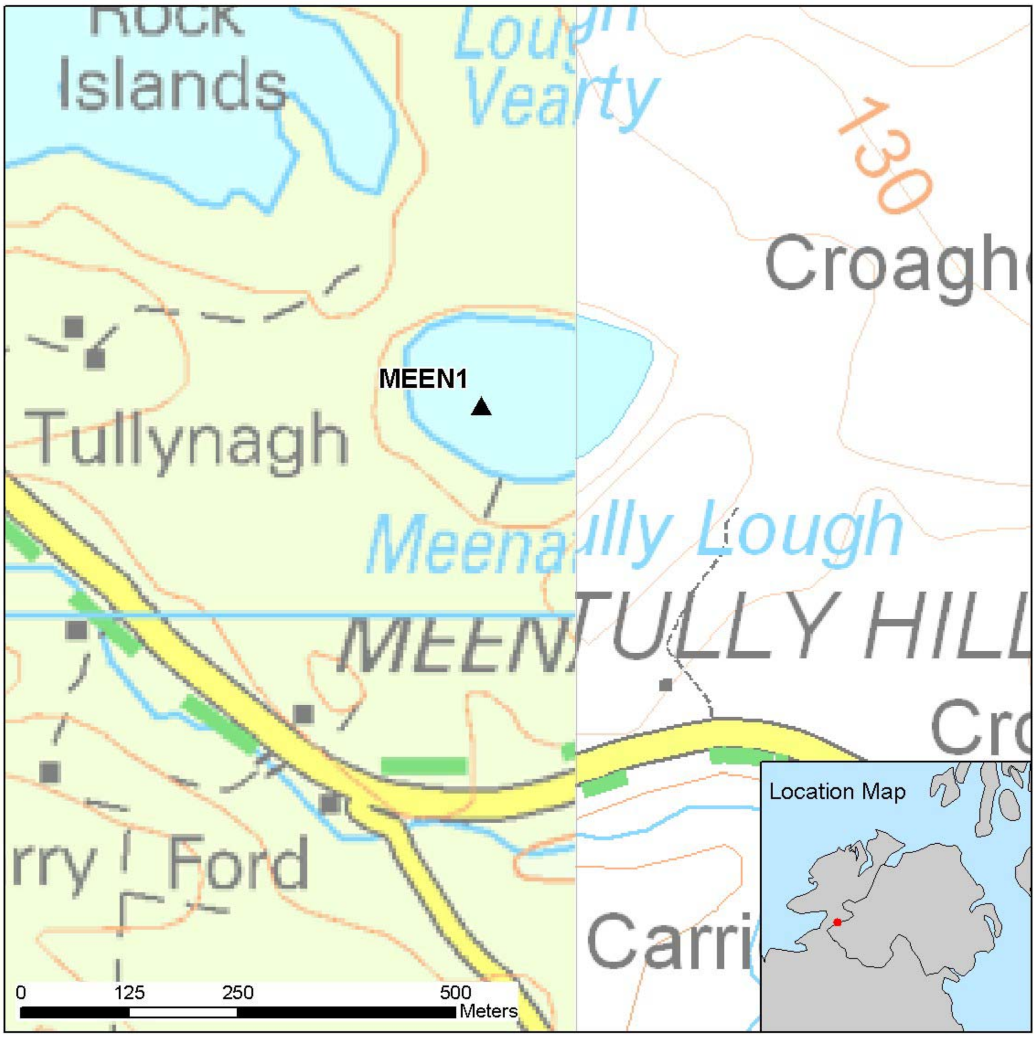
The poverty of plant remains make it difficult to comment on changes in the wider submerged plant community. Despite the low numbers of remains there is a striking similarity with the patterns at Kilroosky, in that there is a general shift from the dominance from water-lily to *Chara* remains. The ^{210}Pb data suggests that the top 10 cm were disturbed or mixed to some extent, this may explain the presence of *Chara* in the surface sediments when no charophytes were recorded in Knockballymore C Lough in the most recent contemporary survey (Goldsmith *et al*. 2008) or a previous survey carried out on 02/08/1988 (NILS). The cladoceran data are less equivocal and strongly indicate that the lake has declined in ecological quality. There was a shift away from a diverse assemblage containing numerous plant associated species characteristic of lakes with a species rich macrophyte community (Jeppesen *et al*. 2000) to an assemblage in the top two samples, containing fewer species, including *B. longirostris*, *A. affinis* and *A. quadrangularis* which are characteristic of increased turbidity and fewer submerged macrophyte species.

Pettigoe plateau

Two sites were sampled on Pettigoe (Table 1 & Figure 1), Meenatully Lough and Lough Rushen.

Meenatully Lough

Figure 45 Map of Meenatully Lough and coring site

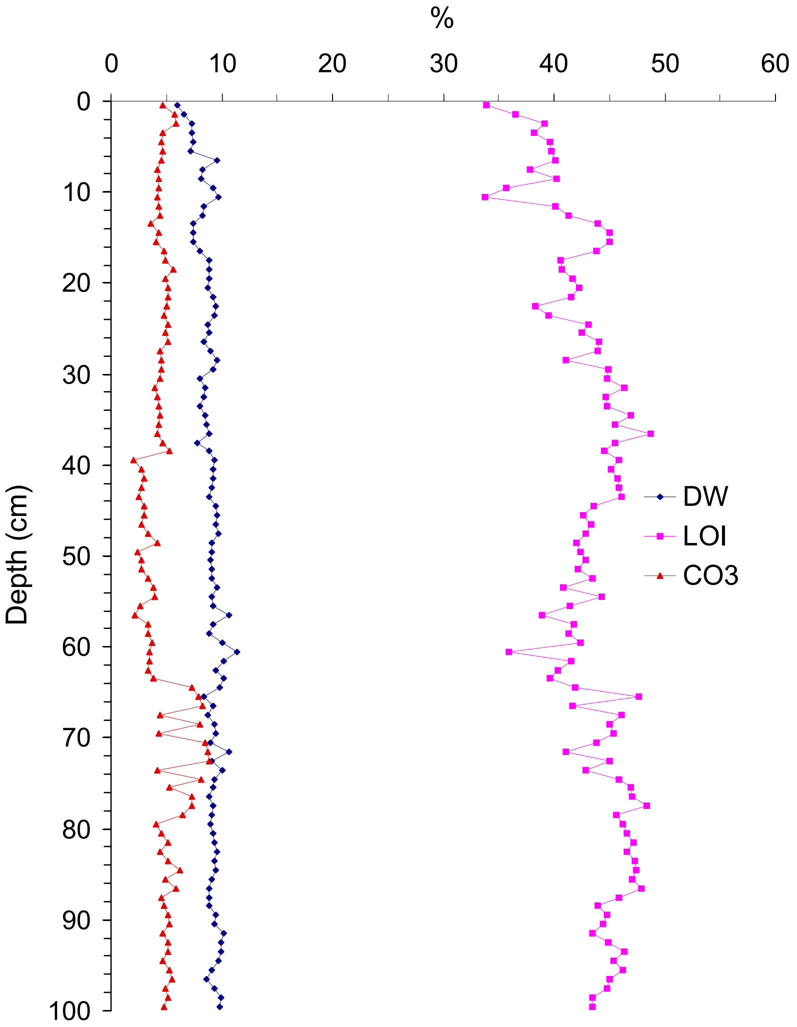


Meenatully Lough lies within a catchment of shallow peats and small areas of exposed bedrock. The water, although slightly brown, was clear enough during the survey to give a Secchi depth reading of 1.90 m and the site has aquatic vegetation extending to a depth of 1.60 m. The surface area of the lough is approximately 4.2 ha. Classified as: Annex 1 type: H3130: Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea* (Goldsmith *et al*. 2008).

MEEN1 lithostratigraphy

The profile of MEEN1 is not rich in distinguishing features (Figure 46). There is little large scale variation in any of the parameters along the length of the core. There was a slow and slight decline in the organic matter (%LOI) of the core. Dry weight (DW) did not vary, but above the 5 cm mark there was a slight decline. Carbonate varied little with a period of very slight decline between 65 and 40 cm.

Figure 46 Lithostratigraphy of MEEN1

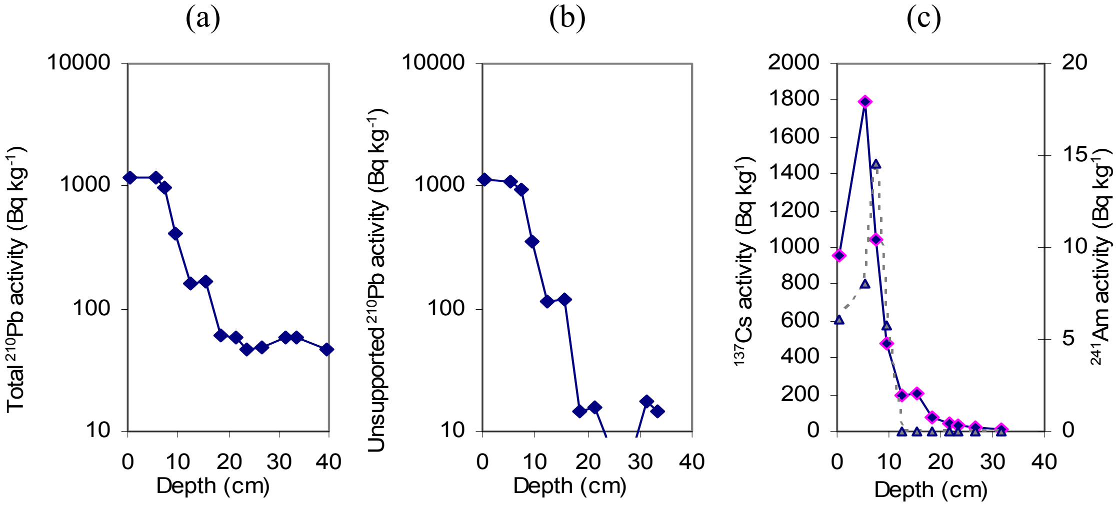


MEEN chronology

Lead-210 Activity

Total 210Pb activity reached equilibrium with the supporting 226Ra at a depth of about 27 cm. The unsupported 210Pb activity declined irregularly with depth (Fig 47), with significant non-monotonic features at 12-16 cm and 18-22 cm. There was little net decline in unsupported 210Pb activity in the surface 6 cm, indicating an increase in sedimentation rates in recent years

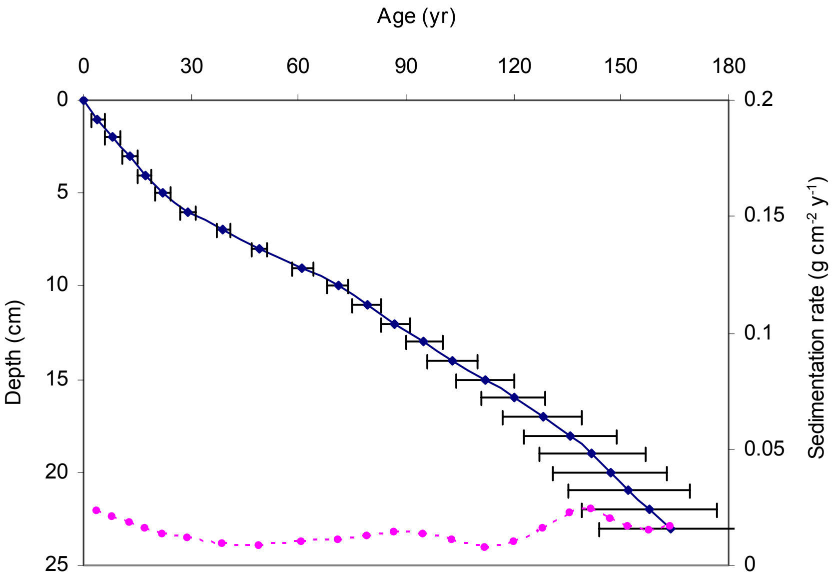
Figure 47. Fallout radionuclide concentrations in the Meenatully Lough core MEEN1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.



Artificial Fallout Radionuclides

The 137Cs activity versus depth showed a single well-resolved peak at 5.5 cm, and the 241Am activity was high in the top 10 cm section and showed a single well-resolved peak at 7.5 cm. The peak at 241Am records is derived from the 1963 fallout maximum from the atmospheric testing of nuclear weapons, the 137Cs peak at 5.5 cm is probably due to fallout from the 1986 Chernobyl accident.

Figure 48 Radiometric chronology of the Meenatully Lough core MEEN1 showing the CRS model ^{210}Pb dates and sedimentation rates.



Summary

The non-monotonic variation in unsupported 210Pb activity of the core has precluded use of the CIC model. 210Pb chronologies were calculated using the CRS dating model (Appleby & Oldfield, 1978). This put the 1963 layer at c. 7.5 cm, which was in good agreement with the 241Am record, and the 1986 layer at c. 5 cm, which was in good agreement with the 137Cs peak, suggesting the CRS model fits this core. The unsupported 210Pb flux was calculated to be 286 Bq m-2 y-1 in the core, suggesting a certain degree of sediment focussing occurred at the coring location. Sedimentation rates calculated using unsupported 210Pb show that sedimentation rates fluctuated a little throughout the last c. 170 years with average value at 0.015 g cm-2 yr-1 (Table 9)

Table 9 210Pb chronology and sedimentation rates of the Meenatully Lough core MEEN1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2007	0				
1	0.0722	2003	4	2	0.0234	0.295	4.6
2	0.1526	1999	8	2	0.0209	0.262	4.7
3	0.233	1994	13	2	0.0185	0.228	4.8
4	0.3135	1990	17	2	0.016	0.195	4.9
5	0.3939	1985	22	2	0.0136	0.162	5
6	0.483	1978	29	2	0.0113	0.128	5.3
7	0.5808	1968	39	2	0.009	0.095	5.9
8	0.6814	1958	49	2	0.0085	0.085	7.3
9	0.7847	1946	61	3	0.0097	0.097	9.7
10	0.8845	1936	71	3	0.0111	0.114	12.8
11	0.9808	1928	79	4	0.0126	0.135	16.9
12	1.0771	1920	87	4	0.0142	0.156	20.9
13	1.1676	1912	95	5	0.0136	0.151	23.6
14	1.2524	1904	103	7	0.0107	0.12	25
15	1.3372	1895	112	8	0.0078	0.09	26.3
16	1.4229	1887	120	9	0.0096	0.109	40
17	1.5097	1879	128	11	0.016	0.177	65.9
18	1.5963	1871	136	13	0.0225	0.245	91.9
19	1.6883	1865	142	15	0.0239	0.258	101.2
20	1.7855	1860	147	16	0.0202	0.215	93.8
21	1.8828	1855	152	17	0.0165	0.172	86.5
22	1.9804	1849	158	19	0.0153	0.157	87.4
23	2.0785	1843	164	20	0.0165	0.169	96.7

MEEN1 biological data

The zonation of the three different groups analysed, plant macrofossils (Figure 49), cladocerans (Figure 50) and diatoms (Figure 51) showed fairly distinct zonations. Whilst macrofossils and cladocerans had shifts in fairly similar places within the core, the diatom assemblages changed at different times, in particular the change in the first zone occurred later in the record.

MEEN1 plant macrofossils

Zone 1 (90-62 cm)

The samples in zone 1 were dominated by *Isoetes lacustris* and to a lesser extent *Isoetes echinospora*. *Lobelia* seeds and *Potamogeton* remains were also evident throughout the zone. Oospores of *Nitella* morphotype A and B were particularly high in the lowermost sample decreasing in abundance towards the top of the zone. Small amounts of *Chara* oospores morphotype A were also found in zone 1.

Zone 2 (62-7 cm)

Isoetes lacustris prevailed throughout zone 2 but decreased in abundance towards the top of the zone. *Isoetes echinospora* was only evident in the lower section of zone 2, as were the *Potamogeton* species remains and *Chara* oospores morphotype A. *Lobelia* seeds persisted throughout zone 2 but at reduced abundances in comparison to zone 1. *Nymphaeaceae trichosclereids* remains appeared in the record at 45cm and 32cm but were missing from the rest of the core samples. Oospores of *Nitella* morphotype A increased in abundance throughout the zone reaching a maximum abundance 356 oospores at 11cm. Oospores of *Nitella* morphotype B also reach maximum abundances within zone 2 of 11,350 oospores at 32cm. These numbers are extremely high and must represent growth of *Nitella* combined with a relatively slow accumulation rate.

Zone 3 (7-0 cm, post 1970 AD)
Species diversity decreased in zone 3 with the loss of all the *Potamogeton* remains, *Nymphaeaceae trichosclereids*, oospores of *Nitella* morphotype B and *Chara* oospores morphotype A. *Isoetes lacustris*, *Isoetes echinospora,* and *Lobelia* were present in the lower section of the zone but are absent from the uppermost sample. Oospores of *Nitella* morphotype A were present but limited in number within this zone.

MEEN1 cladoceran stratigraphy

Zone 1 (90-50 cm)
The basal zone had a relatively diverse assemblage dominated by *A. affinis*, which had a relative abundance of 40%. Other dominant remains were *B. coregoni* and *D. hyalina* agg. ephppia and *C. piger.*

Zone 2 (50-10 cm)
The shift between zone 1 and 2 was characterised by an increase in *D. hyalina* agg. and an increase in species richness with perhaps the occurrence of more plant associated species, such as *Rhynchotalona falcata, M. dispar* and *G. testudinaria*.

Zone 3 (10 – 0 cm)
In the final zone there was a decline in *A. affinis* and an increase in *Alonella nana*, there was also a shift from a very large abundance of *D. hyalina* agg. to the smaller bodied *B. longirostris* and *Ceriodaphnia* spp. ephippia. In contrast to this shift to smaller bodied pelagic species the largest bodied *Daphnid, D. magna* occurred in the top most sample, however the abundance was very small compared to the numbers of *D. hyalina* in zone 2.

MEEN1 diatom stratigraphy

Zone 1 (90-37 cm)
Zone 1 was dominated by the benthic species *Fragilariforma virescens* var. *exigua* and *Staurosira construens* var. *venter* and the planktonic species *Cyclotella radiosa*. Several other *Cyclotella* and *Aulacoseira* species (*C. ocellata* (small), *Cyclotella ocellata*, *Aulacoseira ambigua* and *Aulacoseira distans*) were also present within zone 1 and all increased slightly towards the top of the zone. PCA axis 1 scores decreased towards the top of the zone.

Zone 2 (37-15 cm)
The percentages of *Cyclotella radiosa, C. ocellata* (small), *Aulacoseira ambigua* and *Aulacoseira distans* decreased in zone 2, with corresponding increases in *Cyclotella ocellata* and *Staurosira construens* var. *venter. Fragilariforma virescens* var. *exigua* remains throughout this zone

Zone 3 (15-0 cm)
Levels of *Fragilariforma virescens* var. *exigua* increased towards the surface of the core, with a corresponding decrease in *Staurosira construens* var. *venter.* The percentages of the *Cyclotella* and *Aulacoseira* species were also reduced towards the top of the core. There were slight increases in *Frustulia rhomboides, Achnanthidium minutissimum* and *Navicula vitiosa* in this zone.

Figure 49 Summary stratigraphy of plant macrofossil remains from MEEN1

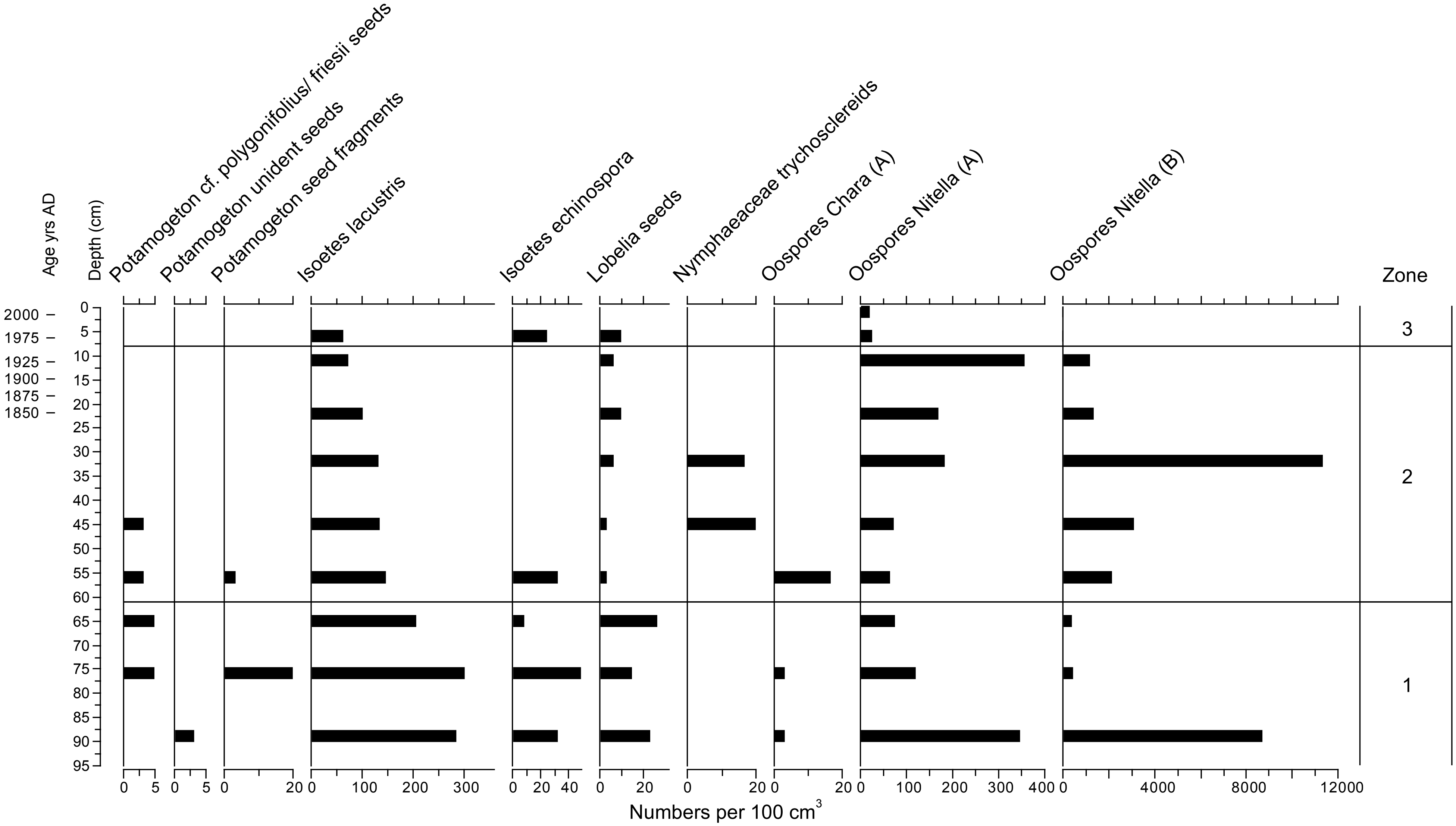


Figure 50 Summary cladoceran stratigraphy from MEEN1

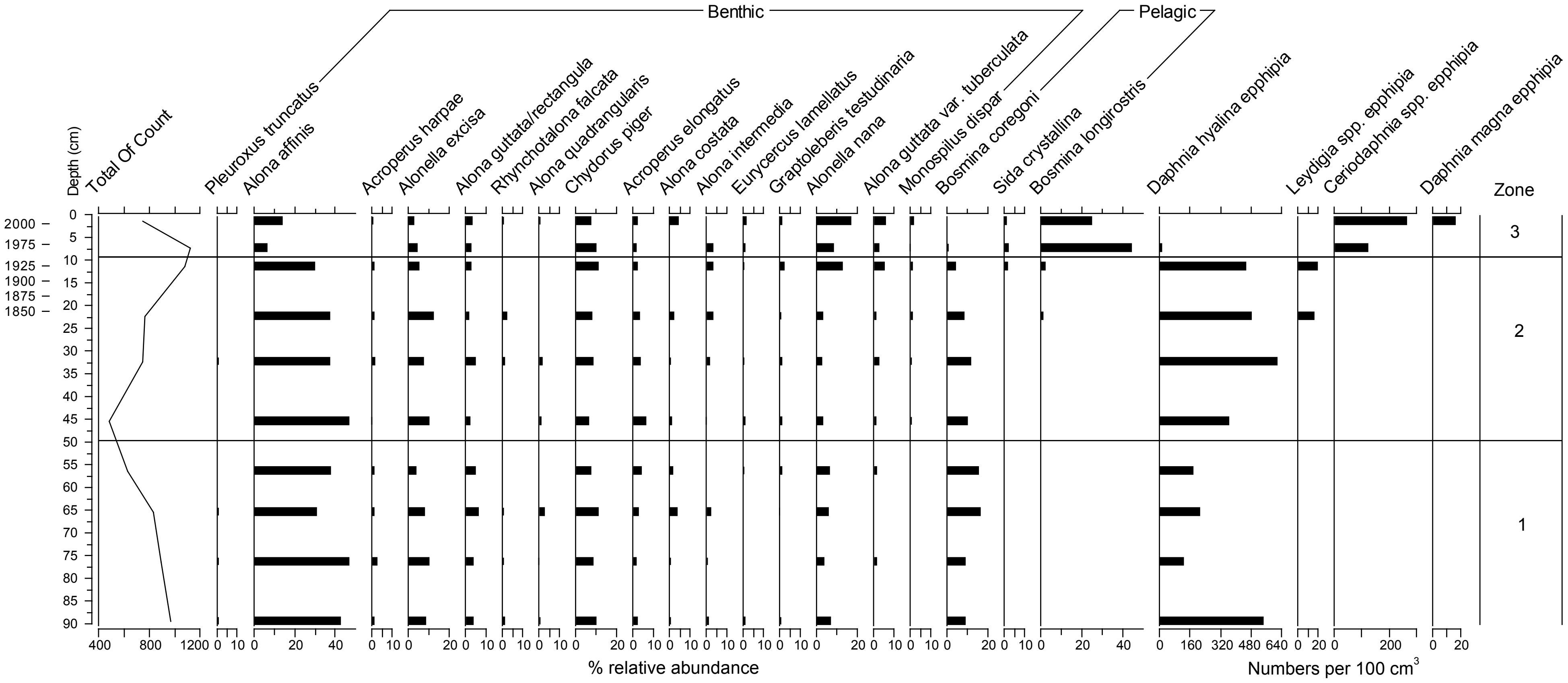
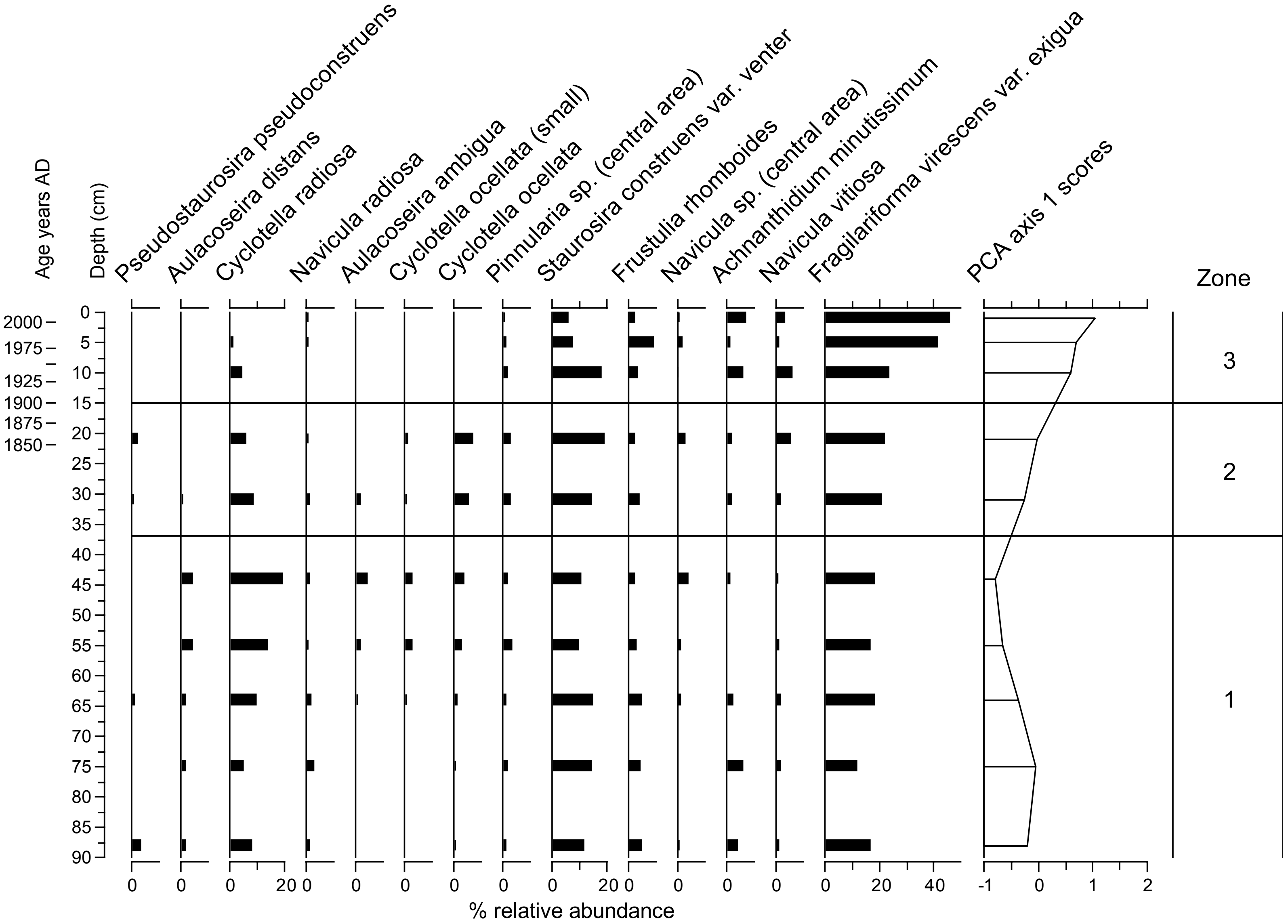


Figure 51 Summary diatom stratigraphy from MEEN1



MEEN1 interpretation

The fossil record for MEEN1 was extremely abundant, particularly in terms of plant remains. Several thousand oospores per 100 cm^3 were found, which are some of the highest densities found using this technique. Comparison of the macrofossil data from the top zone with the two most two most recent surveys (Table 10) shows that the macrofossil data reflects the submerged aquatic community relatively well. Indeed the macrofossil record indicates the presence of both species of *Isoetes,* whereas the contemporary surveys only found *I. lacustris*. *Littorella uniflora* was not recorded the sediments as it leaves few or no macro-remains. Aside from this the frequent and abundant species were recorded.

Table 10 Contemporary aquatic macrophyte community composition for Meenatully Lough.

Submerged and floating vegetation	% occurrence 2006 (n=34)*	DAFOR 1988 (NILS)
Isoetes lacustris	38	F
Juncus bulbosus	9	O
Littorella uniflora	18	O
Lobelia dortmanna	59	A
Menyanthes trifoliata	9	
Potamogeton polygonifolius	+	
Sparganium angustifolium		R
Sphagnum spp. (aquatic)	9	

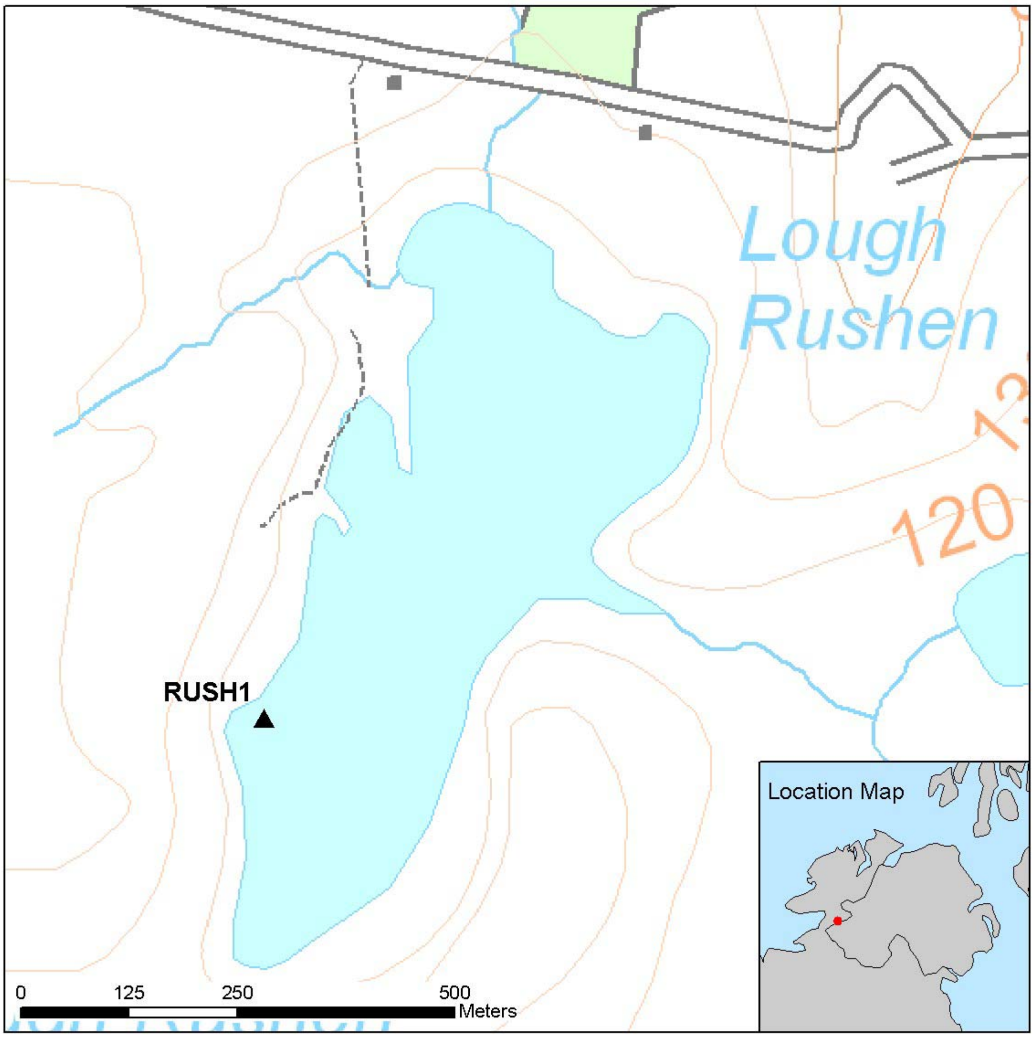
* Based on presence / absence data from all vegetated plots in the wader and boat based surveys
A "+" denotes the presence of a species, but which was not recorded within the survey transects
A "?" is given where identification to species level was not achieved in the 1988 survey data.

The data strongly indicate that the site has undergone a shift in community composition over the length of the core. The cladoceran and diatom data suggest that the lough has always had a significant planktonic production with numerous remains of planktonic species throughout the core *D. hyalina* agg. and *Cyclotella radiosa* in the cladoceran and diatom record respectively. In contrast to more shallow lakes this appears to have had little adverse impact on the macrophyte flora as is evinced by the rich macrofossil assemblage for the lower section of the core. The change in assemblages between zones 1 and 2 may be the result of slight enrichment showing an increase in productivity as with a slight shift along the gradient from oligotrophic to mesotrophic as species richness may have increased and the abundance of the more oligotrophic species *I. lacustris* and *L. dortmanna* appeared to have declined. The final change which has occurred in the last 50 years saw the loss of *Chara* and the probable loss of *Nitella,* there was a concomitant shift in the cladoceran assemblage to dominance by planktonic taxa such as *B. longirostris* and *Ceriodaphnia* spp. and in the benthic species *C. piger* increased in abundance. The shift in the diatom data, i.e. the decrease in *Cyclotella* and increase in *Fragilariforma virescens* var. *exigua* may suggest a decrease in pH/ calcium content, which had a very low value in June 2006 (pH 4.6) (Goldsmith *et al.* 2008). This accords well with the other data, such as the shift away from Charophytes and perhaps the loss of *D. hyalina* agg. Thus, whilst it does not appear the site is acidified, in terms of very low pH, it may well have undergone a significant decline in alkalinity most likely resulting from acid deposition.

Lough Rushen

Lough Rushen lies within a catchment of open heathland, underlain by shallow peats and with small areas of exposed bedrock The surface area of the lough is approximately 23ha. Classified as: Annex 1 type: H3130: Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea.*

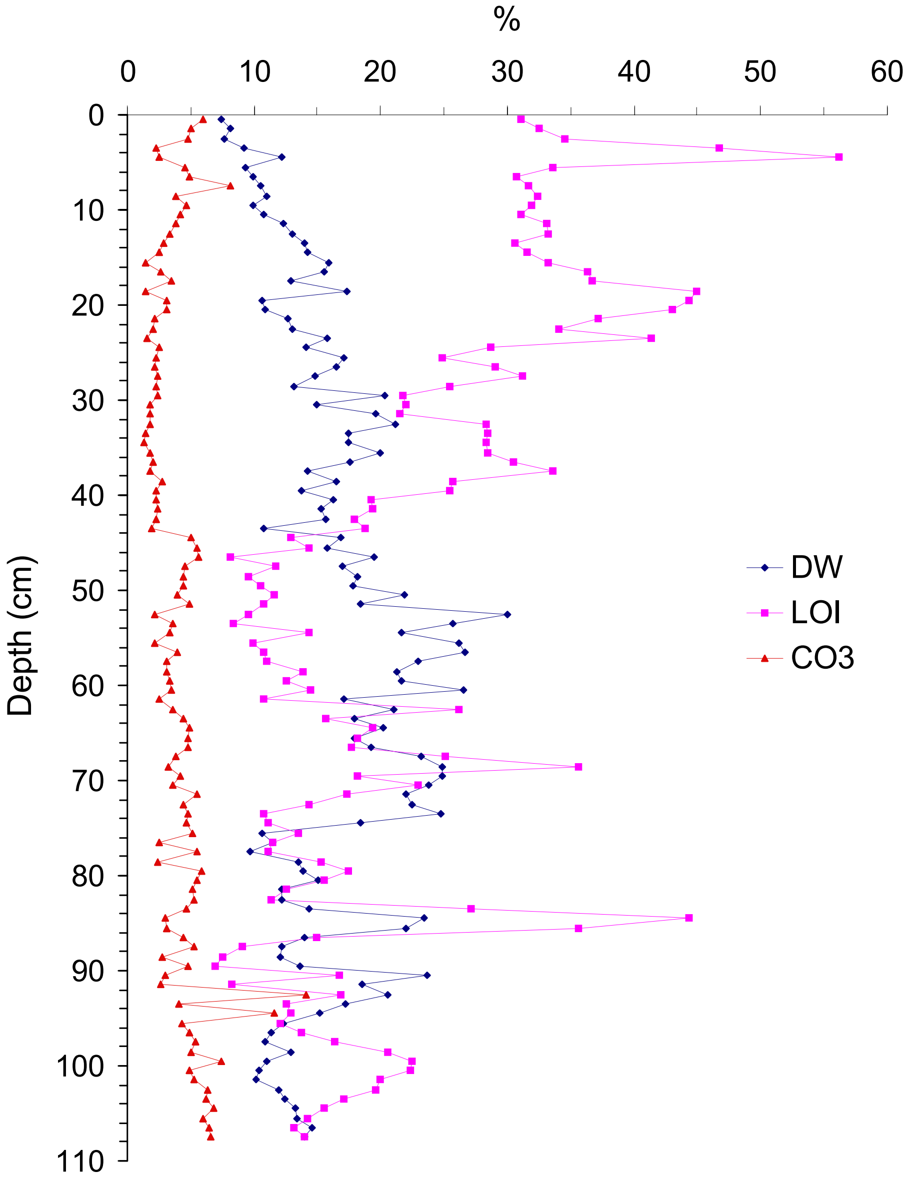
Figure 52 Map of Lough Rushen and core site



RUSH1 lithostratigraphy

The details of coring depth and location for RUSH1 can be found in Table 1 and Figure 52.There was a large amount of variation in the physical properties of RUSH1 (Figure 53). There was a general increase in organic matter (%LOI) up the core, but values were very variable. A notable feature was the decline in %LOI from 60 to 45 cm with a rise in the % dry weight at that time. Above 45 cm the %LOI rose to the surface but with a large amount of variation involved in that rise.

Figure 53 RUSH1 lithostratigraphy



RUSH1 chronology

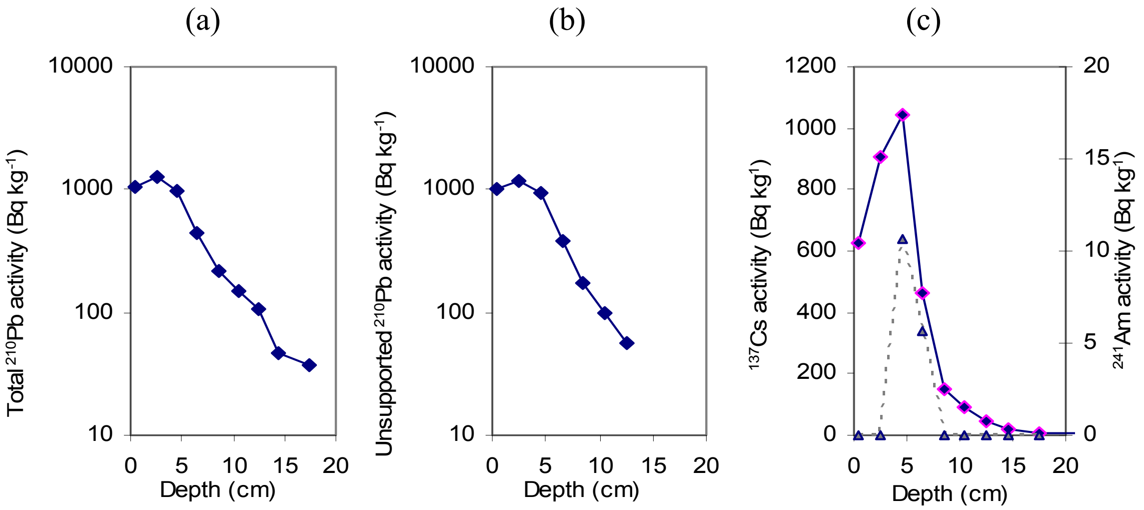
Lead-210 Activity

Total 210Pb activity appeared to reach equilibrium with the supporting 226Ra at a depth of about 13 cm. Overall, the unsupported 210Pb activity declined irregularly with depth (Fig 54), the highest activity was at 2.5 cm. The profile appeared to be divided into two sections: the unsupported 210Pb activity declined more or less exponentially from 3-13 cm, indicative of a relatively uniform sedimentation rate. In contrast, there was little decline from 2.5 cm to the surface, suggesting an increase in sedimentation rates in recent years

Artificial Fallout Radionuclides

The 137Cs activity versus depth showed a single well-resolved peak at 4–5 cm, and the 241Am activity was high from 4.5–6.5 cm, as the latter are derived from the 1963/64 fallout maximum from the atmospheric testing of nuclear weapons, the 1963/1964 layer should be at 4.5-6.5 cm section.

Figure 54 Fallout radionuclide concentrations in the Lough Rushen core RUSH1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.



Summary

Use of the CIC model was precluded by the non-monotonic variation in unsupported ^{210}Pb activity of the core. ^{210}Pb chronologies calculated using the CRS dating model put the 1963/4 layer between 5-5.5 cm, which was in good agreement with the ^{241}Am and ^{137}Cs records. The CRS model calculated sedimentation rates using unsupported ^{210}Pb data showed that sedimentation rates have been relatively stable from the 1860s up to the 1970s, (Figure 55, Table 11) but the sedimentation rates have significantly increased in the last few decades.

Figure 55 Radiometric chronology of the Lough Rushen core RUSH1 showing the CRS model ^{210}Pb dates and sedimentation rates.

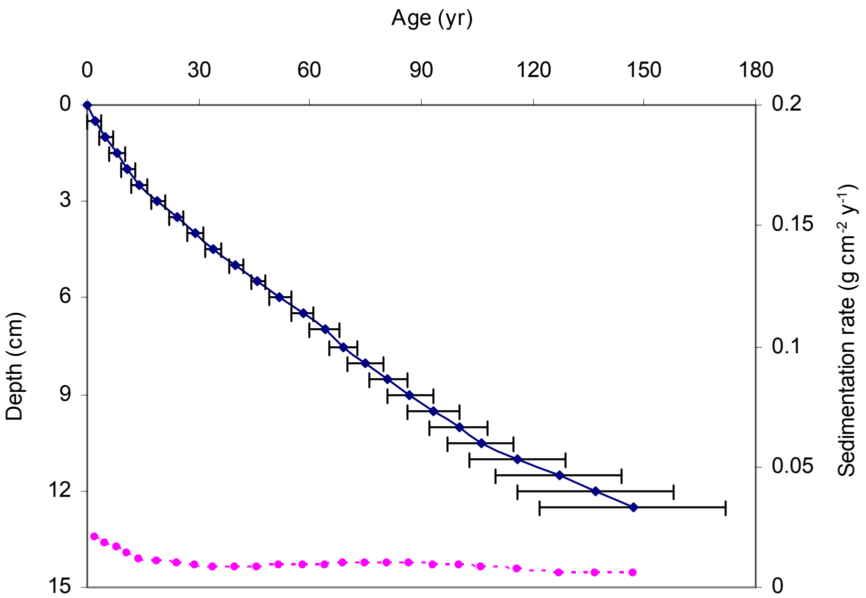


Table 11 210Pb chronology of the Lough Rushen core RUSH1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2007	0				
0.5	0.0425	2005	2	2	0.0205	0.226	4.6
1	0.0887	2002	5	2	0.0183	0.2	4.7
1.5	0.1349	1999	8	2	0.0162	0.175	4.8
2	0.1812	1996	11	2	0.014	0.149	4.9
2.5	0.2274	1993	14	2	0.0118	0.124	5
3	0.2767	1988	19	2	0.0109	0.113	5.4
3.5	0.3259	1983	24	2	0.01	0.102	5.8
4	0.3752	1978	29	2	0.0091	0.091	6.2
4.5	0.4244	1973	34	2	0.0082	0.08	6.6
5	0.4767	1967	40	2	0.0084	0.082	7.6
5.5	0.529	1961	46	2	0.0087	0.083	8.6
6	0.5813	1955	52	3	0.009	0.085	9.6
6.5	0.6336	1949	58	3	0.0093	0.086	10.6
7	0.6888	1943	64	4	0.0095	0.087	12.1
7.5	0.7441	1938	69	4	0.0098	0.088	13.7
8	0.7994	1932	75	5	0.0101	0.09	15.3
8.5	0.8546	1926	81	5	0.0103	0.091	16.9
9	0.9135	1920	87	6	0.0098	0.085	21.4
9.5	0.9723	1914	93	7	0.0093	0.079	25.9
10	1.0311	1907	100	8	0.0088	0.074	30.4
10.5	1.09	1901	106	9	0.0083	0.068	35
11	1.1524	1891	116	13	0.0072	0.058	37.6
11.5	1.2149	1880	127	17	0.0062	0.048	40.2
12	1.2773	1870	137	21	0.0062	0.037	42.8
12.5	1.3397	1860	147	25	0.0062	0.027	45.3

RUSH1 biological data

The remains in RUSH1 were very variable abundance for all groups analysed, with both very low and high abundances and in the case of the diatoms some dissolution.

RUSH1 plant macrofossils

Zone 1 (100-35 cm)

The lowermost sample was dominated by a very large number of *I. lacustris* megaspores reaching a maximal abundance of 1806 spores per 100 cm^3 in the lowest sample. Smaller numbers of *Lobelia* seeds, *Nitella* oospores morphotype A and B, *Potamogeton* cf *friesii* seeds and *Potamogeton* unidentified seeds were also present in the lowest core sample. *I. lacustris* megaspores persisted throughout the rest of the zone but in reduced numbers. The presence of *Lobelia* was limited to only one other sample in zone 1 at 50cm, whilst *Potamogeton* remains were absent throughout the remainder of the zone. Remains were very patchy in this zone.

Zone 2 (35-0 cm)

The lower section of zone 2 was dominated by the large number of *Nitella* oospores morphotype B reaching abundances of 13,433 oospores per 100 cm^3 at 31cm. *Lobelia* seeds also increased in number and occurred regularly in this section of the core reaching maximum abundances of 40 seeds per 100 cm^3 at 31cm. A broad-leaved *Potamogeton* species, *Potamogeton* cf *natans* also appeared in the lower section of the zone. *Nitella* oospores morphotype B remains decreased in the upper section of zone 2 and *I. lacustris* spores remained at low abundances throughout the zone. The aquatic macrofossil remains in the top two core samples 10 and 1cm (representing post ~1925AD) were sparse, with only a few oospores of *Nitella* (B) and *Chara* (A) remaining.

RUSH1cladoceran stratigraphy

Zone 1 (100-45 cm)

In the first zone of RUSH1 the density of cladocerans was very low. Those species present were generally benthic, with *A. affinis* and *C. piger* dominant. The pelagic *B. coregoni* was present throughout the zone.

Zone 2 (45-12 cm)

The was an increase in the density of remains in zone 2 with an increase in the relative abundance of *C. piger* and a shift in the planktonic taxa to *D. hyalina* at the expense of *B. coregoni*, the relative abundance of which declined.

Zone 3 (12-0 cm)

The final zone was characterised by a decline in species richness and a shift in pelagic taxa to dominance by *B. coregoni*. The decline in the *D. hyalina* ephippia and *C. piger* in the benthic taxa were the most marked.

RUSH1diatom stratigraphy

Dissolution evident in the core between 24cm-59cm samples. Samples at 30cm and 38cm there were insufficient diatoms to form a meaningful count.

Zone 1 (100-70 cm)

Zone 1 was dominated by various planktonic *Cyclotella* species (*C.* aff. *comensis, C.* cf *radiosa, C. distinguenda* var. *unipunctata* and *C. kuetzingiana* var. *planetophora*) and benthic *Fragilaria* (sensu lato) species (*Fragilariforma virescens* var. *exigua, Staurosira construens* var. *venter*). The *Cyclotella* species tended to increase towards the top of the zone.

Zone 2 (70-37 cm)

C. cf *radiosa* and *Pinnularia/ Navicula* spp (dissolved) increased in abundance in zone 2 with corresponding decreases in *C. distinguenda* var. *unipunctata. Fragilariforma virescens* var. *exigua* and *Staurosira construens* var. *venter* also increased slightly in zone 2. These species changes are reflected in the slightly higher PCA axis 1 scores in zone 2. Several species in zone 1 and 2 were found to be slightly dissolved.

Zone 3 (37-0 cm)

Numbers of *C.* cf *radiosa* and *Fragilariforma virescens* var. *exigua* decreased in zone 3 with corresponding, but slight, increases in several other *Cyclotella* species (*C. kuetzingiana* var. *planetophora, C.* aff. *comensis* and *C. pseudostelligera*) and *Aulacoseira ambigua*. *Staurosira construens* var. *venter* and *Achnanthidium minutissmum* increased to maximum abundances in zone 3. There were also increases in *Cyclotella pseudostelligera* and *Asterionella formosa* in the surface sample. PCA axis 1 scores decreased substantially, but remain relatively constant, in zone 3.

Figure 56 Summary stratigraphy of plant macrofossil remains from RUSH1

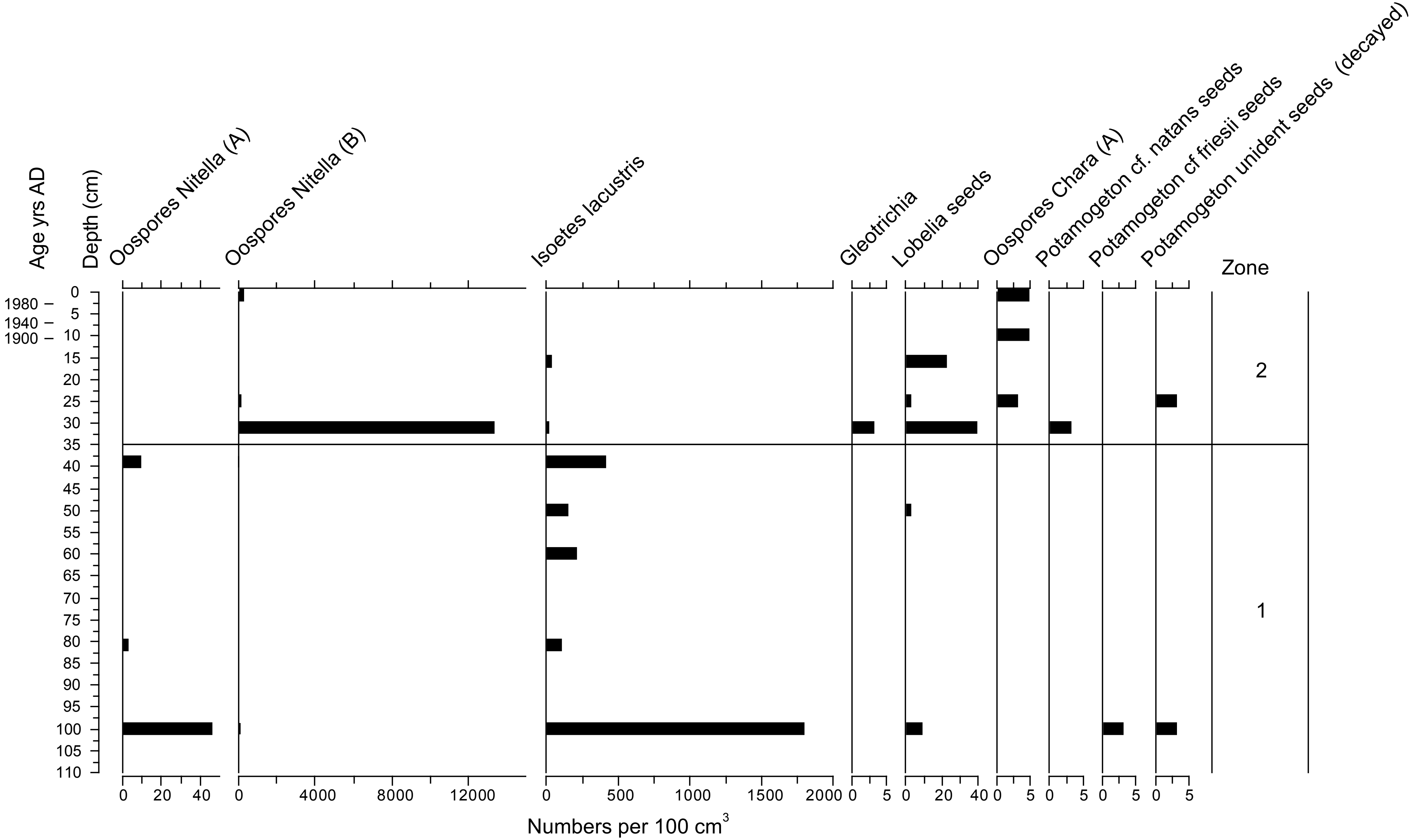


Figure 57 Summary cladoceran stratigraphy from RUSH1

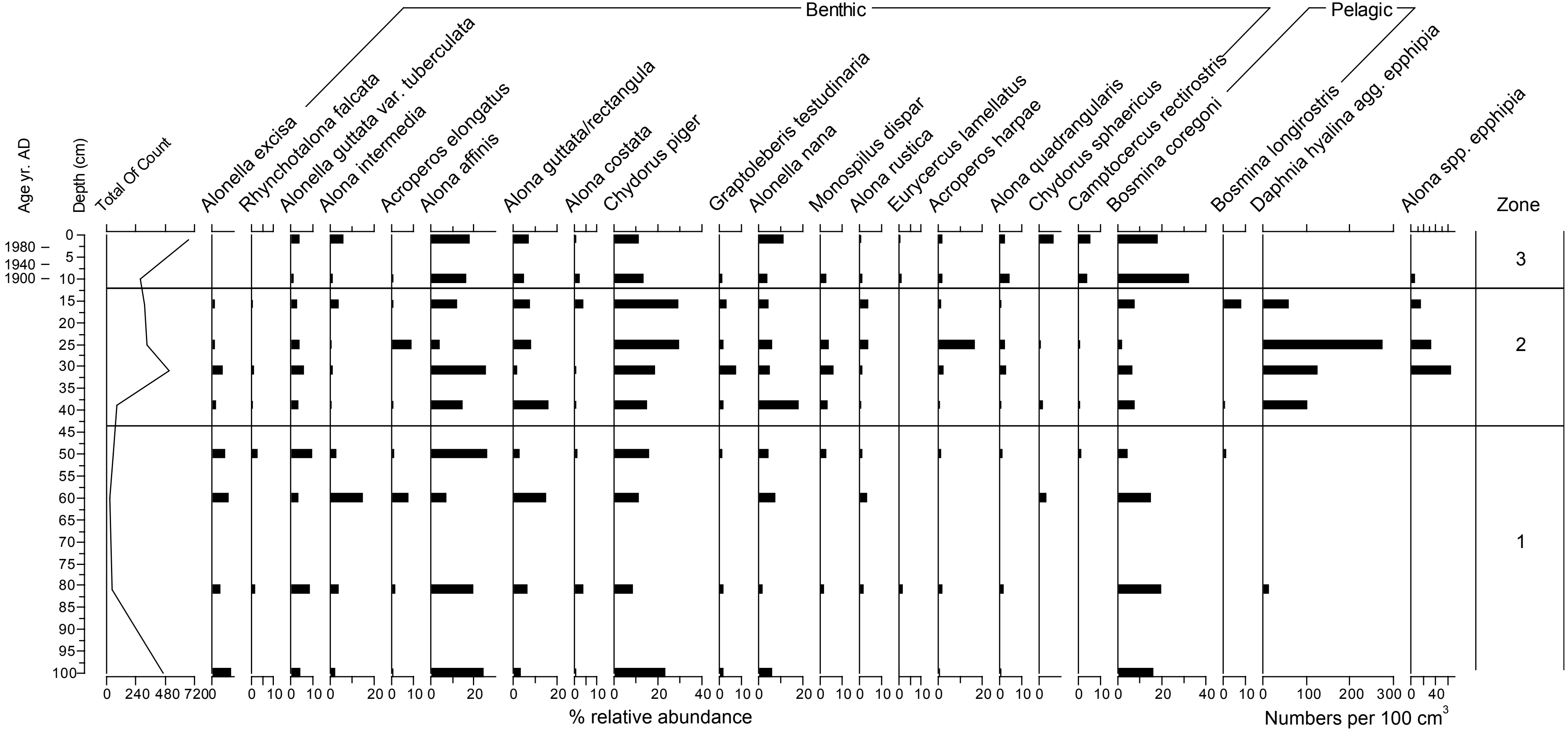
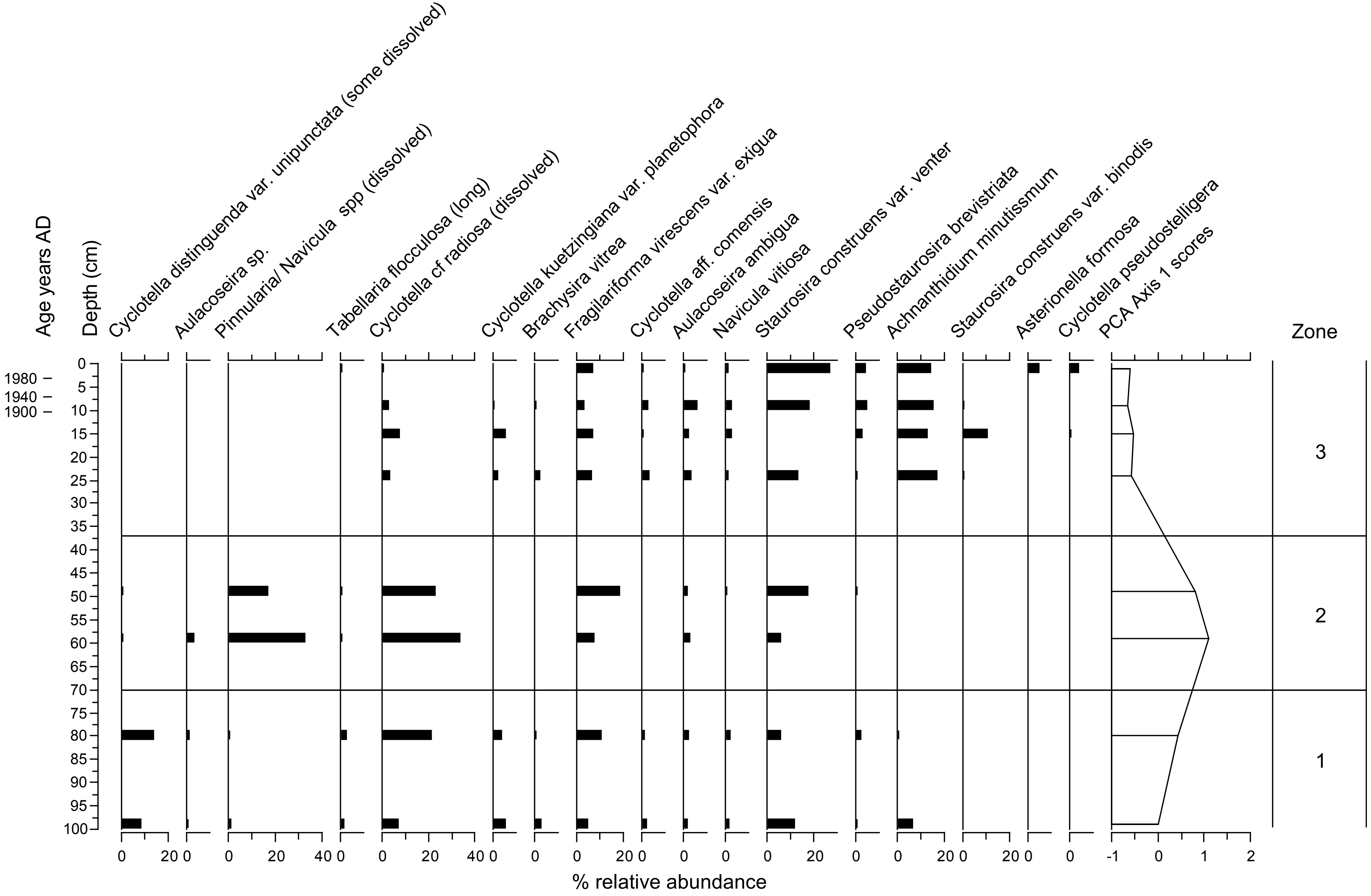


Figure 58 Summary diatom stratigraphy from RUSH1



RUSH1 interpretation

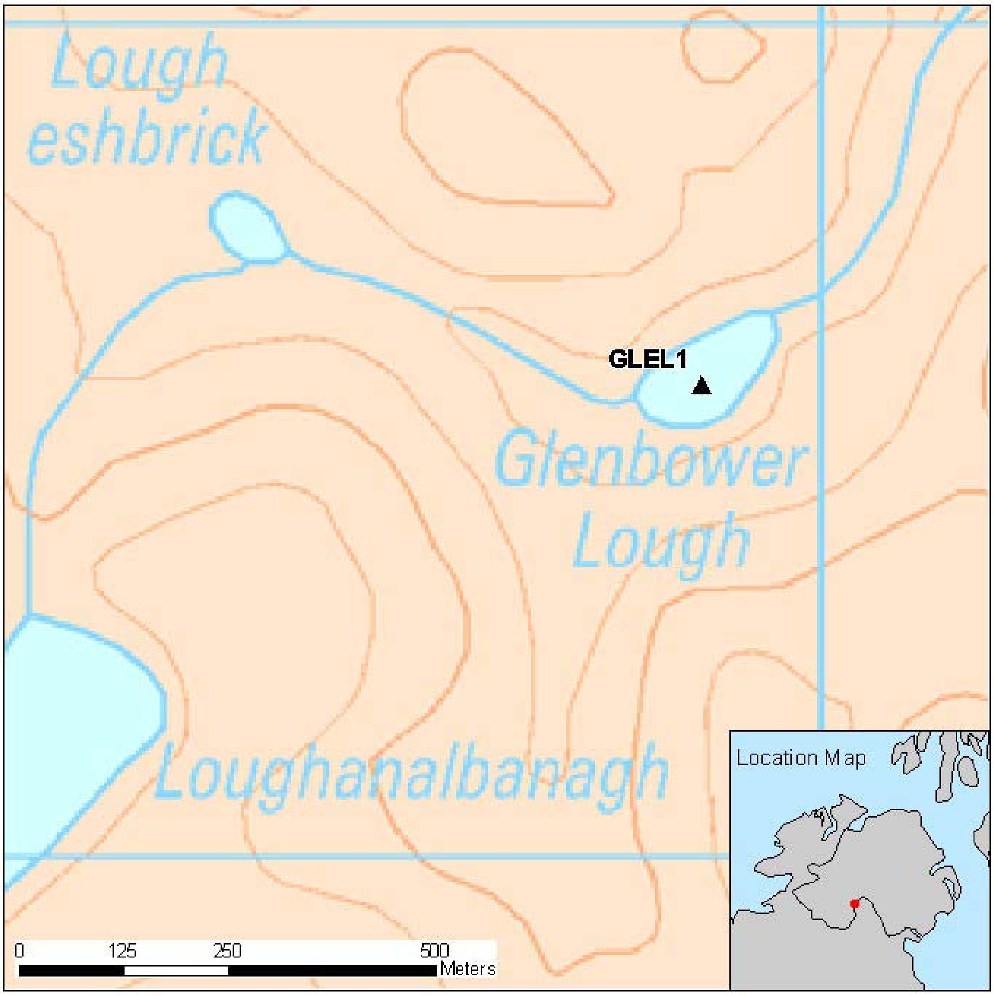
This was a difficult core to interpret as there are few remains but those that do occur, in particular for the macrofossils varied greatly in number. There was also a large area of the core, between 95 and 55 cm with very few macrofossil remains, where diatoms were dissolved and cladocerans remains were sparse.

The assemblages above 45 cm indicate a lough with some planktonic production but a relatively healthy submerged plant flora, to be expected for a relatively deep site such as Lough Rushen. The shift in the upper zone above 10 cm , corresponding to the last 50 to 100 years, suggest a shift from an oligotrophic to a mesotrophic flora, with *I. lacustris* and *L. dortmanna* remains lost from the sediment record. The shift in the cladoceran assemblage from *D. hyalina* to *B. coregoni* is more difficult to interpret and may result from changes in the food-web of the site, as this shift is associated with an increase in zooplanktivorous fish density (Brooks & Dodson 1965). Whether the effects of reduced grazing pressure with the removal of the larger Daphnids has cascaded down the trophic levels resulting in increased algal crop is difficult to ascertain. The contemporary measurements of chlorophyll-*a* were perhaps a little high over the summer period in 2006 (Goldsmith *et al*. 2008), suggesting the site may be at risk.

Slieve Beagh

Glenbower Lough

Figure 59 Map of Glenbower Lough and coring site

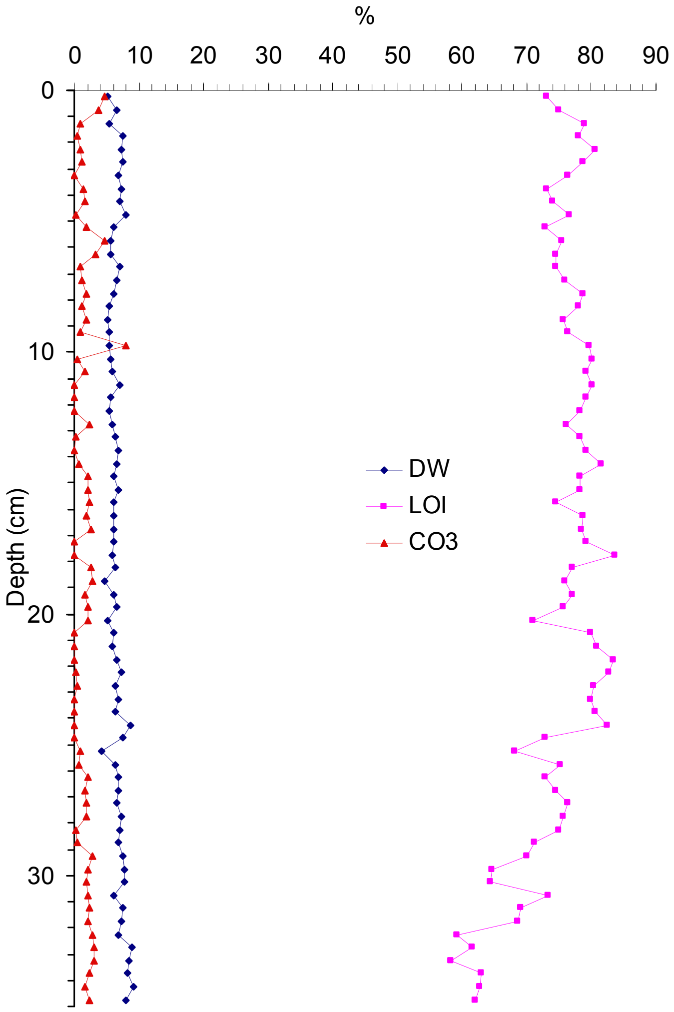


Glenbower Lough is a shallow water body (2.5 m) lying within a peat dominated catchment and has typically brown water for this site type. Classified as: Annex 1 type: H3160: Natural dystrophic lakes and ponds. As a dystrophic water body, Glenbower Lough supports a moderately diverse aquatic macrophyte flora. However, macrofossil analysis was not considered good value and therefore only diatom analysis was conducted.

GLEL1 lithostratigraphy

The details of coring depth and location for GLEL1 can be found in Table 1 and Figure 59. The lithostratigraphy of the core did not vary greatly along its length (Figure 60). The organic content gradually rose from an already high 60% to >70% along the length of core.

Figure 60 GLEL1 lithostratigraphy

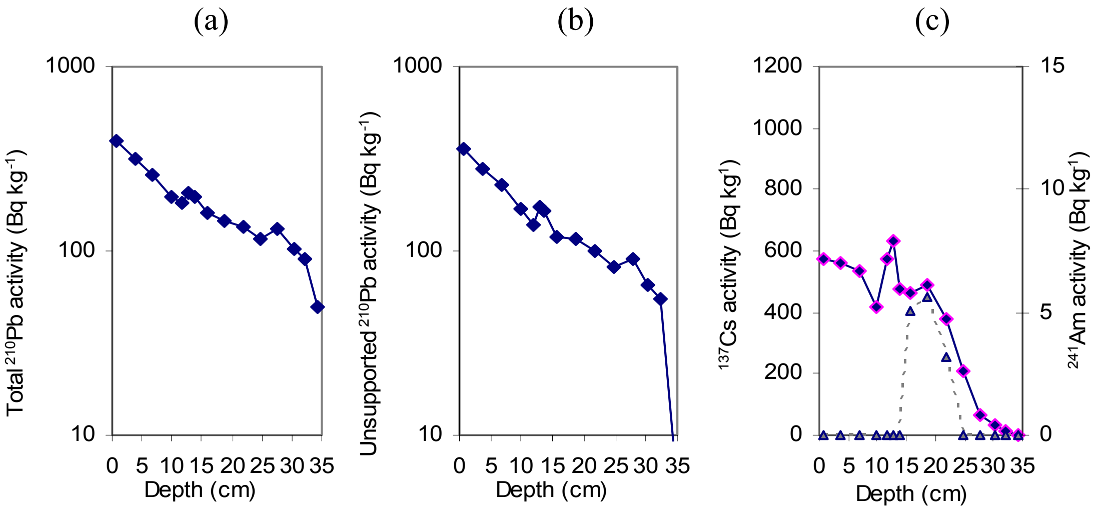


GLEL1 chronology

Lead-210 Activity

Total 210Pb activity appeared to reach equilibrium with the supporting 226Ra slightly below the base of the core. The unsupported 210Pb activities declined more or less exponentially with depth (Figure 61), but there were some non-monotonic variations and there was a sharp drop at the bottom, indicating an increase in sedimentation rates towards the base of the core and then a relatively uniform sedimentation period from c. 25 upwards to the surface of the core (Figure 61).

Figure 61 Fallout radionuclide concentrations in the Glenbower Lough core GLEL1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.



Artificial Fallout Radionuclides

The 137Cs activity versus depth showed two peaks at 12.75 and 18.75 cm. The 137Cs activity between 6.75 and 11.75 cm were relatively low, referring to unsupported 210Pb activity in this section suggests these low values may be due to slight sediment dilution. The 12.75 cm peak probably records the 1986 Chernobyl accident; however, if there was some dilution above 12.75 cm, the 1986 layer would be at a slightly shallower depth than 12.75 cm. The 18.75 cm is derived from 1963/64 fallout maximum from the atmospheric testing of nuclear weapons, this was supported by the presence of traces of 241Am at about the same depth.

Summary

Use of the CIC model was precluded by the non-monotonic variation in unsupported 210Pb activity. 210Pb chronologies were calculated using the CRS dating model (Appleby & Oldfield, 1978). The CRS dating model put the 1963/4 layer in 19-20 cm, which was in agreement with the 137Cs record. The CRS model dates 1986 at 10 cm, which was higher than the 12-13 cm suggested by the 137Cs record. The discrepancy may be due to a slumping of sediment just above 12 cm, which the increased sedimentation rates above 12 cm suggest. This caused little net decline in unsupported 210Pb activities in this section. The unsupported 210Pb flux is calculated to be 105 Bq m-2 y-1 in the core. Sedimentation rates calculated using unsupported 210Pb showed that sedimentation rates increased from the bottom of the core upwards, and were relatively stable in the top part of the core but relatively high in 8-12 cm section (Figure 62, Table 12).

Figure 62 Radiometric chronology of the Glenbower Lough core GLEL1 showing the CRS model ^{210}Pb dates and sedimentation rates

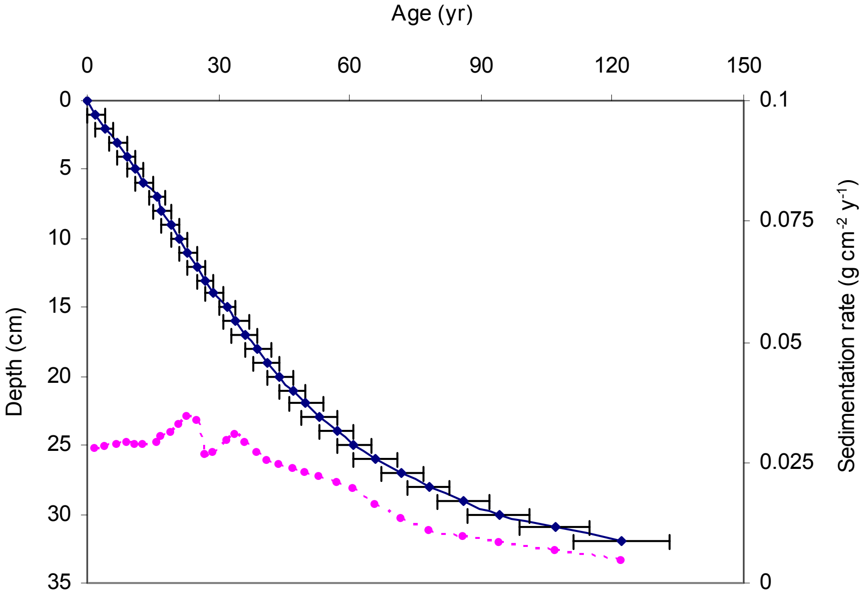


Table 12 210Pb chronology of the Glenbower Lough core GLEL1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2007	0				
1	0.0615	2005	2	2	0.0279	0.442	9.4
2	0.1251	2003	4	2	0.0283	0.446	10.3
3	0.1887	2000	7	2	0.0286	0.45	11.2
4	0.2524	1998	9	2	0.0289	0.454	11.7
5	0.3166	1996	11	2	0.0288	0.46	11.1
6	0.3808	1994	13	2	0.0288	0.466	10.5
7	0.4434	1991	16	2	0.029	0.478	10.3
9	0.5591	1988	19	2	0.0313	0.538	12.8
10	0.6167	1986	21	2	0.0327	0.568	14.5
11	0.6734	1984	23	2	0.0345	0.596	17.3
12	0.7313	1982	25	2	0.0336	0.568	19.3
14	0.8589	1978	29	2	0.0268	0.402	17.3
15	0.9257	1975	32	2	0.0294	0.433	16.7
16	0.9933	1973	34	3	0.0309	0.45	16.7
17	1.0634	1971	36	3	0.0289	0.422	18.5
18	1.1335	1968	39	3	0.027	0.394	20.3
19	1.2028	1966	41	3	0.0253	0.369	21.5
20	1.2695	1963	44	3	0.0244	0.351	20.9
23	1.482	1954	53	4	0.0218	0.293	22.6
24	1.5585	1950	57	4	0.0209	0.272	24.6
25	1.6362	1946	61	4	0.0194	0.246	26.3
26	1.717	1941	66	5	0.0163	0.207	26.8
27	1.7978	1935	72	5	0.0132	0.167	27.3
28	1.8777	1929	78	5	0.0106	0.134	28.2
29	1.955	1921	86	6	0.0095	0.119	30.4
30	2.0324	1913	94	7	0.0084	0.105	32.7
32	2.2011	1885	122	11	0.0045	0.053	36

GLEL1 biological data

GLEL1 diatom stratigraphy

Zone 1 (35-27 cm - pre 1925 AD)

Several *Eunotia* species were present within zone 1 with *Eunotia incisa* being the most dominant. *Tabellaria flocculosa* (short) and *Staurosira construens* var. *venter* also form a large part of the assemblage in zone 1. Numbers of *Nitzschia palea, Eunotia naegelii, Brachysira vitrea* and *Achnanthidium minutissimum* all decreased towards the top of the zone.

Zone 2 (27-2 cm - 1925-2003 AD)

Staurosira construens var. *venter* increased significantly in this zone reaching its maximal abundance at 12.5cm (~ 1982 AD). *Eunotia incisa* and *Tabellaria flocculosa* (short) decreased within the central section of this zone bracketed by slight increases at the bottom and top of the zone. *Nitzschia palea, Eunotia naegelii* and *Brachysira vitrea* were all absent from this zone.

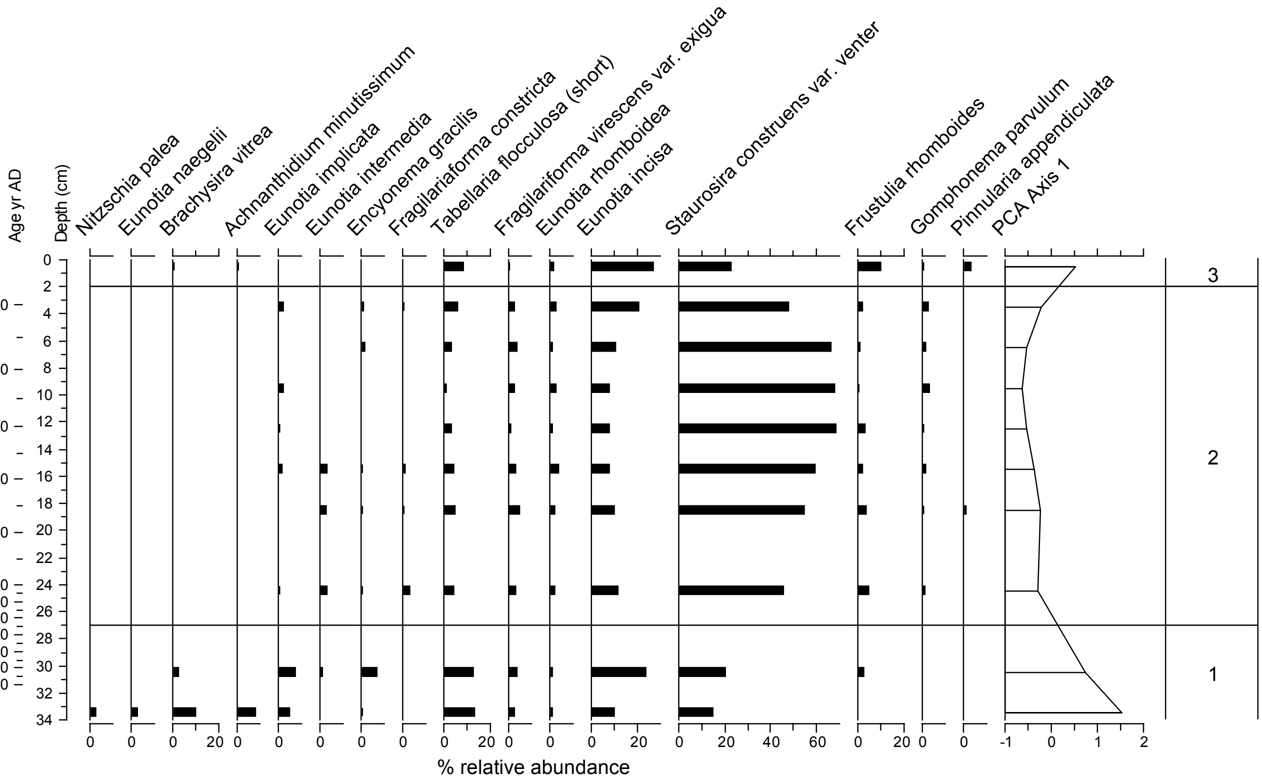
Zone 3 (2-0 cm - 2003-2007 AD)

Staurosira construens var. *venter* decreased in this top sample with corresponding increases in *Frustulia rhomboides, Eunotia incisa* and *Tabellaria flocculosa* (short).

GLEL1 interpretation

The diatom flora of Glenbower Lough were characterised by robust tolerant flora capable of withstanding the lower light conditions of brown-water sites with relatively low pH. The changes may suggest there has been a slight reduction in pH over the time period represented by the core. There does not, however, appear to have been a great deal of change at this site.

Figure 63 Summary diatom stratigraphy from GLEL1

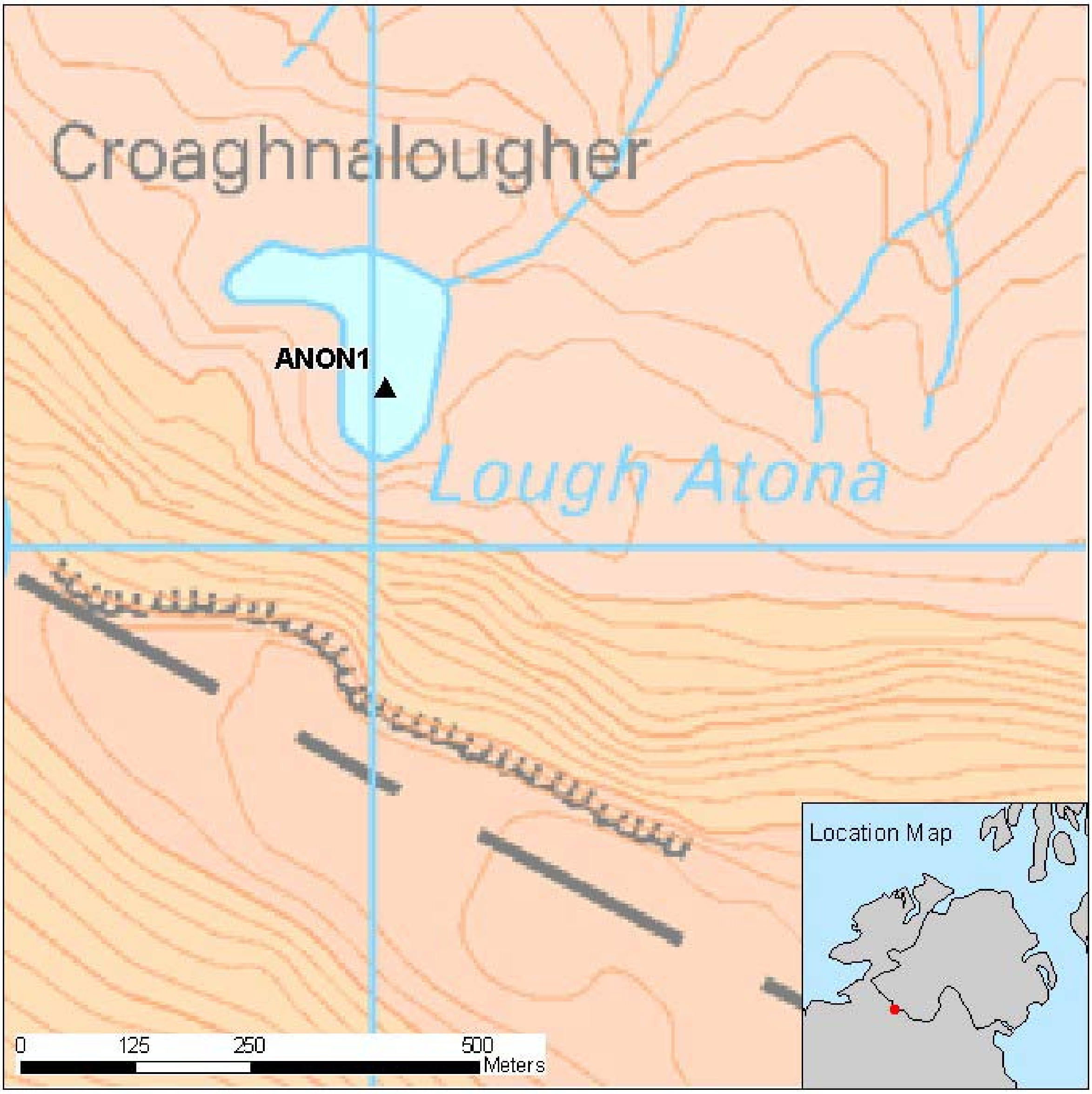


Cuilcagh Mountains

Lough Atona

Lough Atona is for the most part a relatively shallow (6.7m), high altitude water body lying within a heathland catchment with thin organic peat soils and areas of exposed bedrock and screes. The surface area of the lake is 2.5 ha and the site is classified as: Annex 1 type: H3160: Natural dystrophic lakes and ponds.

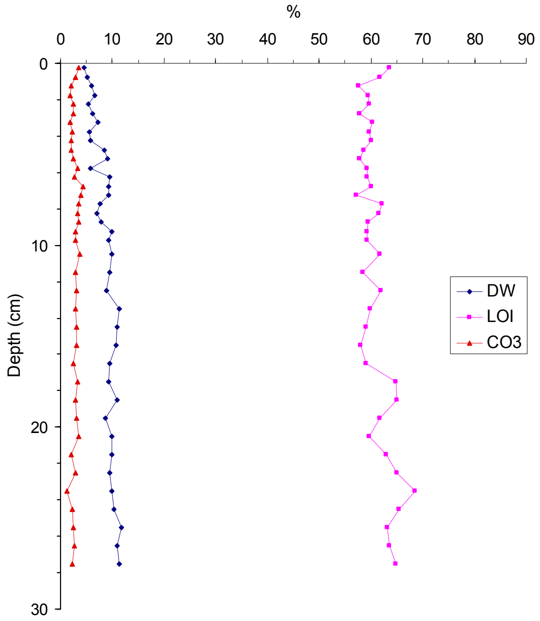
Figure 64 Map of Lough Atona and coring site.



ANON1 lithostratigraphy

The details of coring depth and location for ANON1 can be found in Table 1 and Figure 64. The lithostratigraphy of the core showed little to no change along its length (Figure 65). The organic content of the sediment (%LOI) was relatively high with values around 60%.

Figure 65 ANON1 lithostratigraphy.

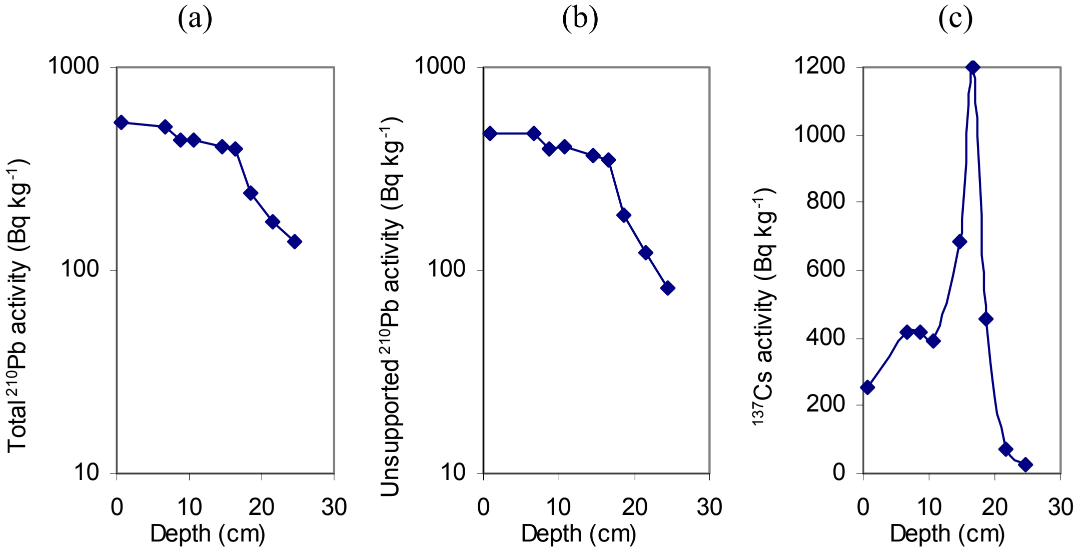


ANON1 chronology

Lead-210 Activity

Total 210Pb activity did not reach equilibrium with the supporting 226Ra at the bottom of the core. Unsupported 210Pb activity, calculated by subtracting 226Ra activity from total 210Pb activity, suggested the core could be divided into two sections (Figure 66). From 0–17 cm, unsupported 210Pb activity declined more or less exponentially with depth, from 18–25 cm unsupported 210Pb activity also declined exponentially with depth, however, the decline rates were different. This suggests that sedimentation rates within each section were relatively stable, but that they changed between sections. Cumulative unsupported 210Pb reached 8749 Bq m-2, which is much larger than the average value in the region for a complete core.

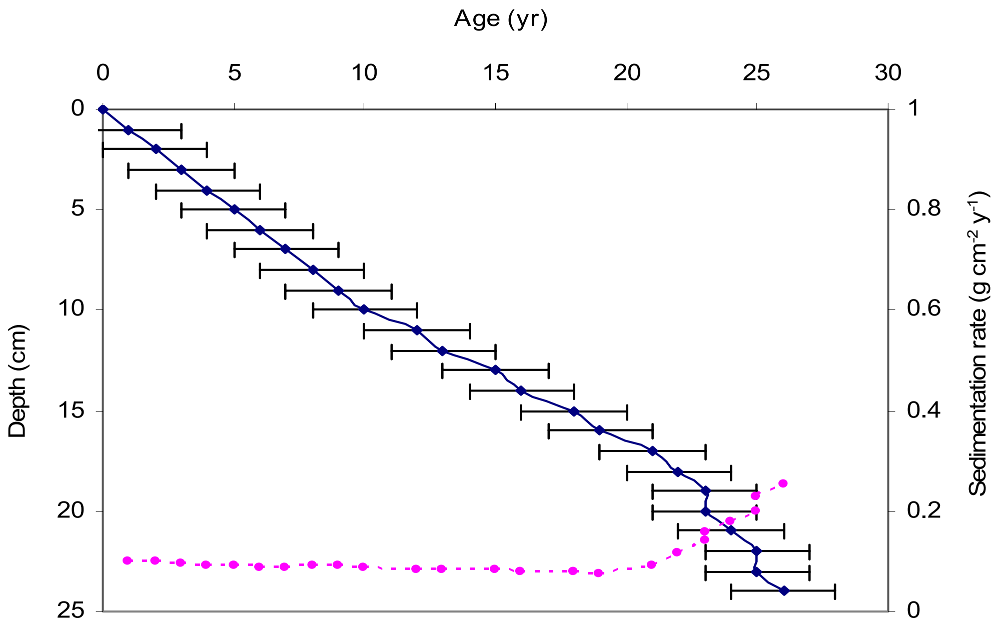
Figure 66 Fallout radionuclide concentrations in the Lough Atona core ANON1 showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.



Artificial Fallout Radionuclides

The 137Cs activity versus depth had a relatively well-resolved sharp peak at 16.5 cm in the core. The very high 137Cs value at peak suggests it is almost certainly derived from the 1986 Chernobyl accident.

Figure 67 Radiometric chronology of the Lough Atona core ANON1 showing the CRS model ^{210}Pb dates and sedimentation rates



Summary

Chronological data were calculated using the CRS dating model. The raw CRS model placed the 1986 depth at 9.5 cm, this was higher than the 1986 depth suggested by the ^{137}Cs record. The final ^{210}Pb dates were calculated using the CRS model and the 1986 layer in the ^{137}Cs record was used as a reference point. Unsupported ^{210}Pb flux in the core was 492 Bq m^{-2} yr^{-1}, suggesting the core has been strongly affected by sediment focussing. Calculated sedimentation rates based on the revised ^{210}Pb dates suggested that sedimentation rates declined in the 1980s, followed by a relatively uniform period. The sediment accumulation rates for this core are really extremely high for a less productive upland lough such as Lough Atona being around 1 cm a year (Figure 67, Table 13). This is most likely to result from sediment focussing at the coring site rather than high autochthonous production.

Table 13 210Pb chronology of the Lough Atona core ANON1.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age	Std			% Std
cm	g/cm^2	AD	yr	±	g/cm^2/yr	cm/yr	±
0	0	2006	0				
1	0.0704	2005	1	2	0.101	1.115	6.7
2	0.1646	2004	2	2	0.099	1.074	6.6
3	0.2587	2003	3	2	0.096	1.033	6.6
4	0.3528	2002	4	2	0.093	0.993	6.5
5	0.447	2001	5	2	0.091	0.952	6.4
6	0.5411	2000	6	2	0.088	0.911	6.4
7	0.6385	1999	7	2	0.087	0.877	6.5
8	0.7459	1998	8	2	0.091	0.862	7.1
9	0.8547	1997	9	2	0.092	0.833	7.6
10	0.9674	1996	10	2	0.088	0.764	7.3

11	1.0822	1994	12	2	0.084	0.709	7.2
12	1.2033	1993	13	2	0.082	0.695	7.5
13	1.3244	1991	15	2	0.081	0.681	7.8
14	1.4455	1990	16	2	0.08	0.668	8.1
15	1.5643	1988	18	2	0.078	0.662	8.2
16	1.6808	1987	19	2	0.077	0.662	8
17	1.7953	1985	21	2	0.09	0.792	7.9
18	1.9078	1984	22	2	0.117	1.05	7.9
19	2.0188	1983	23	2	0.14	1.264	9.2
20	2.1282	1983	23	2	0.159	1.435	11.9
21	2.2376	1982	24	2	0.178	1.606	14.7
22	2.3483	1981	25	2	0.201	1.808	16.5
23	2.4604	1981	25	2	0.227	2.041	17.4
24	2.5724	1980	26	2	0.254	2.274	18.3

ANON1 biological data

ANON1 diatom stratigraphy

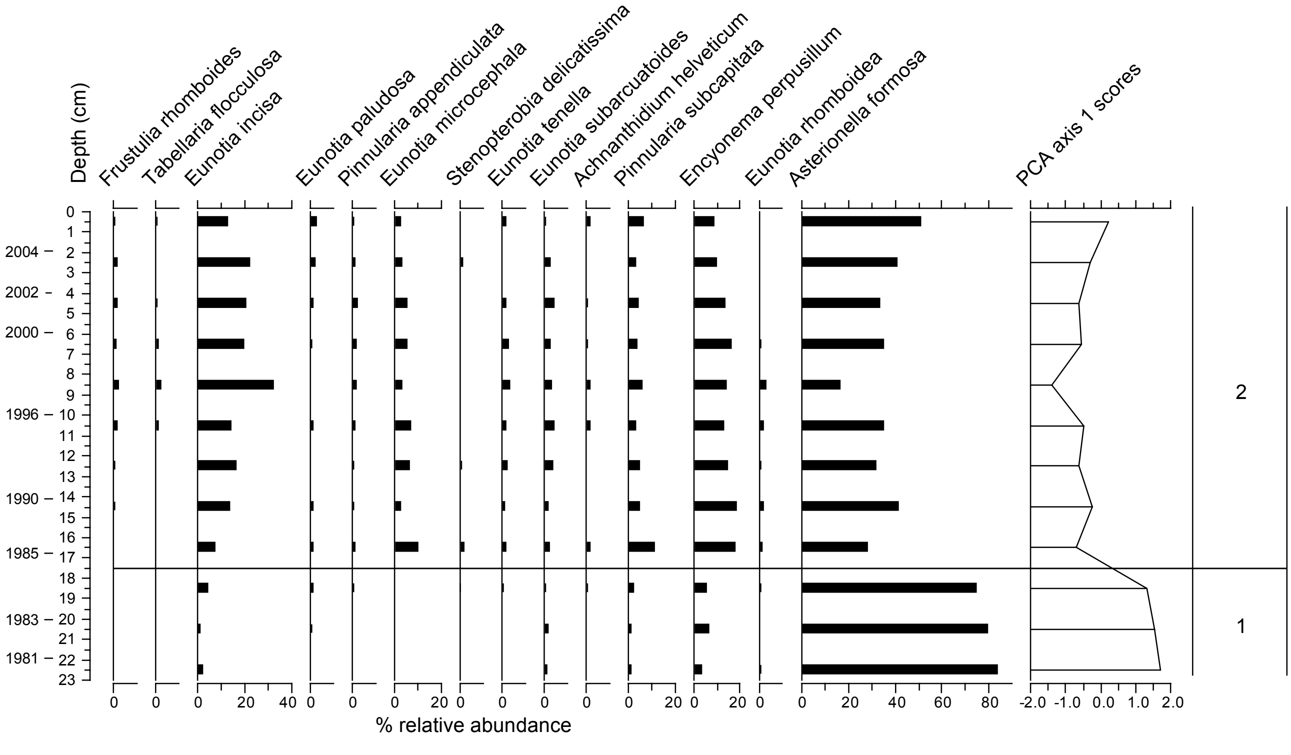
Zone 1 (23-17.5 cm)

The bottom of the core was dominated by *Asterionella formosa* (~70-80%), a planktonic taxon typically associated with circumneutral to alkaline, mesotrophic waters. Occurring alongside at low percentage relative abundances are *Eunotia* spp., *Encyonema perpusillum* and *Pinnularia* spp., all of which are periphytic taxa associated with moderately acid conditions. PCA axis 1 scores were highest in this zone.

Zone 2 (17.5-0 cm)

Zone 2 was also dominated by *A. formosa* but at lower relative abundance (generally 30-40%). The importance of *E. incisa*, *E. perpusillum* (both ~10-20%) and to a lesser extent, *Eunotia microcephala* and *Pinnularia subcapitata* increased in zone 2. At a depth of 8.5 cm, *E. incisa* attained its highest abundance (~30%) and the relative abundance of *A. formosa* decreased to <20%. This was reflected in the low PCA axis 1 score at this depth.

Figure 68 ANON1 diatom stratigraphy



ANON1 interpretation

Diatom preservation was very good throughout core. The time period represented by the core is very short representing only the last 30 years in 24 cm. This is almost certainly the result of sediment focussing at the coring site rather than very high production within the lough. The changes in the diatom assemblage suggest that conditions at the base of the core were perhaps less acidic or that there has been a decline in alkalinity up-core. This would indicate that there has been a decline in productivity over the last 30 years.

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