ECRC

Environmental Change Research Centre

Research Report No. 146

Using novel palaeolimnological techniques to define lake conservation objectives for three Cheshire meres

Final Report to Natural England

H. Bennion, B. Goldsmith, G. Clarke, R. Rawcliffe, N. Rose, S. McGowan, N. Willby, T. Davidson, C. Sayer, V. Panizzo & K. Roe

July 2010

ISSN: 1366-7300

Environmental Change Research Centre
Department of Geography
University College London
Pearson Building, Gower Street
London, WC1E 6BT

Executive summary

This is the final report to Natural England on the project 'Using novel palaeolimnological techniques to define lake conservation objectives for three Cheshire meres': Melchett Mere, Tatton Mere and Comber Mere. The aim is to use existing and recently developed palaeoecological techniques to define reference conditions and assess the condition of selected Sites of Special Scientific Interest (SSSIs) in the Cheshire meres, and thereby assist in the setting of conservation objectives and management goals.

Two sediment cores (one open water and one marginal), approximately 1 m in length, were collected from Tatton Mere and Comber Mere, and a 0.5 m core was collected from the open water zone of Melchett Mere during the period 15-17 February 2010. All cores were sampled at 1 cm intervals throughout and approximately ten samples from each site were analysed for diatoms, Cladocera, macrofossils, and pigments. The cores were dated using the spheroidal carbonaceous particle (SCP) method. An existing diatom-total phosphorus (TP) transfer function was applied to the diatom data to reconstruct the nutrient history of the lakes. Additionally, TP was hindcast for macrophytes by application of a model developed as part of the LEAFPACS project to the macrofossil data.

The dating results suggest that the Melchett Mere record extends back to at least ~1850. Early changes were observed in the sediment core indicative of a deepening of the site during formation of the lake in the early 1900s, which resulted from subsidence of the underlying salt deposits. The most striking changes, however, have occurred since ~1950 with a shift in the diatom flora to one dominated by planktonic taxa typical of relatively productive lakes, an increase in zooplankton species associated with open water, particularly large-bodied pelagic *Daphnia* spp. which suggests plentiful planktonic algae as a food source, and a marked increase in abundance of most pigments. There were also notable increases in both diatom and macrophyte-inferred TP values from ~40 µg L^{-1} in the lower core to ~80 µg L^{-1} in the upper zone. In combination, these shifts signal enrichment of the lake from the mid-1900s with a consequent decrease in plant abundance. Unfortunately it was not possible to assess changes in the plant community of the lake with any confidence owing to the paucity of macrofossil remains in the deepwater core. Nonetheless, the study shows that aquatic plants have always been present at the site and suggests that there might have been a shift from *Chara* to *Potamogeton* taxa, which would be consistent with the eutrophication story. The unusual origin of the site makes it difficult to define reference conditions but, nevertheless, it can be concluded that there has been an increase in pelagic productivity since approximately the mid-1900s consistent with eutrophication.

The open water core from Tatton Mere extends back to ~1800 AD and the marginal core extends back a little further to ~1750 AD. The palaeoecological data indicate that Tatton Mere has been a nutrient-rich lake for the whole of the period represented by the cores with diatom-inferred TP concentrations of ~120-150 µg L^{-1} even in the lower part of the record. However, there were marked changes across a range of indicators from the early 1800s indicative of enrichment, which has continued through the twentieth century. The key changes were the expansion of the eutrophic diatom species *Stephanodiscus parvus* and hence an increase in diatom-inferred TP to ~160-180 µg L^{-1}, a steady increase in pigment concentrations from all algal groups, and shifts in the zooplankton community indicative of increased pelagic productivity. Eutrophication has resulted in marked changes in the aquatic plant community from a structurally diverse flora with abundant Charophytes, nymphaeids and taxa with a mix of seasonalities to a less diverse flora comprised of largely nutrient-rich taxa that

dominate in the early part of the growing season. The most notable changes in the macrofossil record have occurred from the mid-1900s and are, therefore, coincident with the main phase of enrichment in the neighbouring Melchett Mere. There are, however, subtle signs of water quality improvement in the uppermost sample of the Tatton Mere core with a decline in diatom taxa associated with highly nutrient-rich lakes and consequent decrease in inferred TP values to ~100-120 µg L^{-1}, an increase in *Chara* remains and a decline in pigment concentrations. The recent increases in *Daphnia magna* suggest that the absence of top-down grazing by fish has been at least partly responsible for the recent improvements. Tatton Mere was already moderately nutrient-rich at the base of the core and a longer core is required to extend the record and thereby to define pre-enrichment reference conditions for the site. However, the study has provided information on the plant and animal communities that were present in the lake prior to the major eutrophication phase and this will be valuable for setting targets for future management of the site.

The open water core from Comber Mere extends back to ~1800 AD although the chronology is rather speculative. Unfortunately the marginal core from the lake could not be dated by the SCP method and, therefore, the timing of the changes in the macrofossil data could not be established. The study indicates that Comber Mere has been a nutrient-rich lake for the whole of the period represented by the sediment core. Nevertheless the lake was less productive in the past and has experienced recent enrichment starting in ~1900, which has continued to the present day, with notable changes occurring especially from the mid-1900s. The main changes have been a decline in diatom taxa associated with mesotrophic waters and non-planktonic taxa indicative of a favourable light climate, an increase in planktonic diatom species typically found in eutrophic conditions, an increase in diatom-inferred TP concentrations from ~120 to 180 µg L^{-1}, a steady increase in pigment concentrations, a decrease in plant-associated Cladocera species and an increase in pelagic zooplankton taxa indicative of greater pelagic production. The macrofossil data suggest that the lake was dominated by nymphaeids in the past but their abundance decreased in the middle part of the record (date unknown), and that the lake currently supports several pondweeds and some nymphaeids which is in reasonable agreement with recent plant survey data. The sediment records extend back to a point in the past when conditions were less productive than today and, therefore, the data can be used to inform restoration targets for the site.

In summary, all three study sites have experienced enrichment over the period represented by the sediment records, most notably since the mid-1900s. This has manifested itself in an increase in diatom taxa associated with nutrient-rich waters, an increase in the diversity of diatom plankton and consequent extension of the period of planktonic algal growth, an increase in pelagic zooplankton and concomitant decline in those associated with plants, an increase in pigment concentrations, and a decline in plant diversity and structural changes in the plant community. In all cases the palaeoecological data indicate an increase in pelagic productivity over time reflecting more eutrophic conditions than in the past. The findings lead us to conclude that the study sites were relatively nutrient-rich but reasonably stable in the past and they have undergone a period of twentieth century cultural eutrophication resulting in major ecological shifts. A full review of the site histories was beyond the scope of this project and, therefore, the causes of the observed changes have not been fully explored. Nonetheless the timing of the changes in the palaeoecological data is coincident with the onset of more intensive agriculture and/or greater inputs of sewage from expanding populations in the catchments.

For Tatton Mere continued monitoring of the nutrient chemistry, algal populations and the plant community of the site is recommended to see if recent signs of improvement are sustained. While nutrient concentrations are currently considerably lower in Melchett Mere than in Tatton Mere monitoring of nutrients, as well as regular surveys of the plants and algae, is recommended to detect any changes in water quality. Monitoring of Comber Mere is also advised to obtain information on seasonal and inter-annual variation including chemical and biological parameters. The construction of a nutrient budget for Comber Mere is recommended to identify the main sources of nutrients to the lake. At all sites management should focus on reduction of external nutrients at a catchment scale. Equally it is important to prevent an increase in zooplanktivory in the lakes as the currently high *Daphnia* numbers are likely to be a key factor in limiting plankton biomass and, therefore, fish stocking should be avoided.

The study concludes with several recommendations for further work including analyses of longer cores from Tatton Mere and Comber Mere, higher resolution analysis of the existing sediment cores focussing on the last 50 years, further research on the site histories to explore changes in land use, catchment events, nutrient sources, fish populations and any management activity, and analyses of sediment records from other sites to inform Common Standards Monitoring and lake condition assessment.

List of contributors

Helen Bennion, Ben Goldsmith, Gina Clarke, Ruth Rawcliffe, Neil Rose, Tom Davidson, Carl Sayer, Virginia Panizzo and Kevin Roe
ENSIS Ltd. / Environmental Change Research Centre
University College London
Pearson Building
Gower Street
London
WC1E 6BT

Suzanne McGowan
School of Geography
University of Nottingham
University Park
Nottingham
NG7 2RD

Nigel Willby
School of Biological & Environmental Sciences
University of Stirling
Stirling
Scotland
FK9 4LA

Acknowledgments

The authors would like to thank the site managers and owners, and colleagues at Natural England, for permission to carry out the study.

Cover photograph: Comber Mere, Cheshire (February 2010).

Table of Contents

List of Figures

List of Tables

1. SPECIFICATION

1.1 Statement of understanding, purpose and aims of project

The primary objective of this project is to use existing and recently developed palaeoecological techniques to define reference conditions and assess the condition of selected Sites of Special Scientific Interest (SSSIs) in the Cheshire meres, and thereby to assist in the setting of conservation objectives and management goals. There is a government public service agreement (PSA) target for 95% of SSSIs to be in favourable or unfavourable recovering condition by the end of 2010 and consequently Natural England is currently engaged in defining and implementing the necessary management. The outputs of this project will be used to assist progress towards achieving the PSA target.

The three Cheshire Meres selected for study are Tatton Mere, Melchett Mere, and Comber Mere. These form part of the West Midland meres, a group of waterbodies mostly of glacial and periglacial origin scattered across the counties of Shropshire, Cheshire and Staffordshire. The meres and the associated wetlands known as 'mosses' are recognised as an important nature conservation area and many are designated as SSSIs and included within the Midlands Meres and Mosses Ramsar site. The Meres have been described as Britain's naturally eutrophic lakes (e.g. Reynolds & Sinker, 1976), largely owing to the naturally high levels of phosphorus (P) in the drift derived soils, and the long history of blue-green algal blooms (McGowan *et al*., 1999). Nitrogen is scarce relative to P, particularly in the deeper lakes (Moss *et al*., 1994). There has been much debate over whether the meres are indeed naturally rich systems or whether in fact they have simply been impacted over long timescales (Anderson, 1995). Several long term palaeolimnological studies provide evidence of anthropogenically induced eutrophication dating back to at least Medieval times (see Anderson, 1995) whilst sediment studies focusing on the last few hundred years indicate a period of enhanced productivity associated with intensification of agriculture during the 20th century (e.g. Brooks *et al.,* 2001). Given the long history of impact in the region, historical records and palaeoecological studies provide the only means by which past conditions can be reconstructed.

The specific objectives of the project are:

1. To reconstruct the historic plant communities
2. To reconstruct the nutrient history
3. To discuss reasons for the current state of the meres and timing of change in conditions.
4. To suggest possible approaches to restoration.

The project is divided into three main tasks. Task 1 involves the collection, processing and dating of cores from the study sites, Task 2 focuses on diatom analysis and application of a P transfer function to reconstruct the nutrient histories of the lakes, and Task 3 employs macrofossil analysis to determine reference conditions and ecological change in aquatic plant communities. In addition, there are three further aspects to the project: i) the application of modern plant-based training sets, developed as part of the LEAFPACS project (Willby *et al.,* 2009), to the historical macrophyte data to hindcast P for macrophytes, ii) Cladocera analysis to assess changes in the zooplankton communities, and iii) pigment analysis to provide information about past communities of algae or photosynthetic bacteria (e.g. McGowan *et al*., 2005). Further details of these tasks are given in the methods section.

2. METHODS

2.1 Core collection

Two sediment cores (~1 m in length), one from the open water and one from the marginal zone, were collected from Tatton Mere and Comber Mere, and a ~0.5 m core was collected from the open water of Melchett Mere during the period 15-17 February 2010. The cores were expected to represent approximately the last 100-150 years, thereby allowing reference conditions to be defined and recent ecological change to be assessed.

A second core could not be retrieved from Melchett Mere owing to a lack of organic material in the marginal zone. The exact reasons for this are not known but it is most likely associated with the relatively recent origin of the site. The lake is thought to have formed in the early 1900s by a large underground collapse, probably related to water erosion of the underlying Cheshire salt deposits over thousands of years.

Expert judgement, bathymetric data and any previous data on sediment distribution were used to decide on the optimal coring location that maximises the likelihood of obtaining a sound chronology and finding abundant remains of the fossil groups of interest. Summary details of the cores are given in Table 1.

2.2 Extrusion, core description and stratigraphic analyses

The cores were extruded in the field at 1 cm intervals to provide a resolution of approximately a few years per sample, and any visible stratigraphic changes were noted. The percentage dry weight (DW) which gives a measure of the water content of the sediment, the percentage loss on ignition (LOI) which gives a measure of the organic matter content and the percentage carbonate (CO_3) content were undertaken using standard techniques (Dean, 1974; Heiri *et al.,* 2001) on selected sub-samples from each core.

Selected samples from the open water cores were sub-sampled for diatom and Cladocera analysis, and selected samples from the marginal cores of Tatton Mere and Comber Mere and the single core from Melchett Mere were sub-sampled for macrofossil analysis. Previous studies have shown that abundance and diversity of macrofossils are greater in marginal cores than those taken from the deeper open water as heavy remains such as seeds do not travel far from their source plant (Davidson *et al*., 2005; Zhao *et al*., 2006). However, diatom and Cladocera analyses are typically carried out on open water cores from the deepest basin where the full range of habitats including planktonic and non-planktonic forms are well represented (e.g. Battarbee *et al*., 2001). Additionally sub-samples from the open water cores were frozen and delivered to University of Nottingham for pigment analyses. Finally, twenty samples from each of the five cores were sub-sampled and freeze-dried for spheroidal carbonaceous particle (SCP) analyses, the method used here to date the cores.

2.3 Dating

Dating of the cores from each of the three sites was carried out using the well established technique of spheroidal carbonaceous particle (SCP) following the method described in Rose (1994). Dried sediment was subjected to sequential chemical attack by mineral acids to remove unwanted fractions leaving a suspension of

mainly carbonaceous material and a few persistent minerals in water. SCPs are composed mostly of elemental carbon and are chemically robust. The use of concentrated nitric acid (to remove organic material), hydrofluoric acid (siliceous material) and hydrochloric acid (carbonates and bicarbonates) therefore does them no damage. A known fraction of the resulting suspension was evaporated onto a coverslip and mounted onto a microscope slide. The number of SCPs on the coverslip was counted using a light microscope at x450 magnification and the sediment concentration calculated in units of 'number of particles per gram dry mass of sediment' (gDM^{-1}). The criteria for SCP identification under the light microscope followed Rose (2008). Analytical blanks and SCP reference material (Rose, 2008) were included in each batch of sample digestions. Reference concentrations agreed with the expected values while no SCPs were observed in the blanks. The detection limit for the technique is ~100 gDM^{-1} and concentrations have an accuracy of ~ ± 45 gDM^{-1}.

In most cases the dating of the cores followed the method described in Rose *et al.* (1995) whereby three main features of the SCP profile are used to provide dates: the start of the record, the rapid increase in SCP concentration and the peak in SCP concentration. An alternative approach using cumulative SCP inventory profiles (Rose & Appleby, 2005) was applied to the open water core from Tatton Mere as a full SCP record was present, allowing percentiles from the cumulative curve to each be ascribed a date. Dates for each 10-percentile of the cumulative SCP profile, from the start of the record (0%) to the concentration peak (100%), were allocated to the core. Where it is possible to use this latter approach, it is preferable as it provides more dates for each core than the method based on the three features in the profile.

2.4 Diatom analysis

Standard diatom analysis (Battarbee *et al*., 2001) of ten samples per open water core was carried out. At least 300 valves were counted from each sample using a research microscope with a 100x oil immersion objective and phase contrast. Krammer & Lange-Bertalot (1986-1991) was the principal flora used in identification. The diatom data were expressed as percentage relative abundances. The data were entered into Excel spreadsheets and are included as tables in Appendix 1. Diatom data are presented as a series of summary stratigraphic plots showing change in frequency of the major taxa through time, produced using C2 software (Juggins, 2003).

The technique of weighted averaging (WA) regression and calibration, has become a standard technique in palaeolimnology for reconstructing past environmental variables (e.g. ter Braak & van Dam, 1989). A predictive equation known as a transfer function is generated that enables the inference of a selected environmental variable from fossil diatom assemblages, based on the relationship between modern surface-sediment diatom assemblages and contemporary environmental data for a large training (or calibration) set of lakes. This approach has been successfully employed to quantitatively infer lake total phosphorus (TP) concentrations (e.g. Anderson *et al*., 1993; Bennion, 1994; Bennion *et al*., 1996), whereby modern diatom TP optima and tolerances are calculated for each taxon based on their distribution in the training set, and then past TP concentrations are derived from the weighted average of the optima of all diatoms present in a given fossil sample. More recently the technique has been improved by extension to a method called WA partial least squares (WA-PLS) (ter Braak & Juggins, 1993). This method overcomes some of the limitations of simple WA by using the residual correlation in the diatom data to improve the estimates of the taxa 'optima' or regression coefficients, as shown by

Bennion *et al*. (1996). WA-PLS can, however, result in over-fitting and the various advantages and problems of the technique are fully discussed by Birks (1998).

An existing diatom- TP transfer function which includes data from 33 West Midlands Meres (Bennion *et al*., 1996) was applied to the diatom data to reconstruct the nutrient history of the lake (e.g. Bennion *et al*., 2004). This was based on a Northwest European training set of 152 relatively small, shallow lakes (< 10 m maximum depth) with a median value for the dataset of 104 µg TP L^{-1} and a root mean squared error of prediction (RMSEP) of 0.22 and 0.21 $\log_{10}$ µg TP L^{-1} for the WA-PLS one-component (WAPLS1) and two-component (WAPLS2) models, respectively. The reconstruction was implemented using C2 (Juggins, 2003). Currently there is no such model for reconstructing nitrogen (N) concentrations. Nevertheless the diatom-TP inferences can be used to infer changes in overall trophic status of the lakes.

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

Site name	Site code	Site NGR	Core code	Core NGR	Core location	Coring date	Coring water depth (m)	Core length (cm)	Core type	Sampling intervals
Melchett Mere	MELC	SJ751811	MELC3	SJ 75080 81147	open water	15-Feb-10	11.6	48	Tapper	1 cm throughout except for 0-5 cm which is an amalgamated sample
Tatton Mere	SCM41	SJ755801	SCM41E	SJ 75563 80088	open water	16-Feb-10	11.6	119	Tapper	1 cm throughout except for 0-2 cm which is an amalgamated sample
Tatton Mere	SCM41	SJ755801	SCM41F	SJ 75512 80535	marginal, northern end ~100 m offshore	16-Feb-10	5.3	78	Piston	1 cm throughout
Comber Mere	SCM14	SJ590446	SCM14B	SJ 59388 44670	open water	17-Feb-10	11.7	107	Tapper	1 cm throughout
Comber Mere	SCM14	SJ590446	SCM14C	SJ 59400 44518	marginal, eastern end ~40 m offshore	17-Feb-10	4.4	104	Piston	1 cm throughout

2.5 Macrofossil analysis

Macrofossil analysis involves the study of sediment core samples for macro-remains of water plants including various propagules (seeds, fruits, oospores, turions) and vegetative fragments (leaves, stems, cells and spines) that are visible with a standard dissecting microscope up to perhaps 40x magnification (Lowe & Walker, 1997; Birks, 2001). Macrofossil analysis of ten samples per marginal core, selected to cover the period of interest and to enable the pre-enrichment conditions to be determined, was carried out. A measured volume of sediment (~30 cm^3, the exact volume was assessed using water displacement) was analysed for each level. Samples were sieved at 350 and 125 microns and the residues from each were transferred using distilled water to plastic vials for storage. The entire residue from the 350 micron sieve was examined under a stereomicroscope at magnifications of x10-40 and plant and animal macrofossils (zooplankton ephippia) were identified and enumerated. A quantitative sub-sample, approximately one fifth of the sample, from the 125 micron sieve sample was analysed for smaller remains such as leaf spines. All plant material was identified by comparison with herbarium documented reference material. It was not always possible to ascribe remains to species level, thus in some cases an aggregate group of species corresponding to the highest possible taxonomic resolution was used. For example, *Potamogeton pusillus* agg. included remains of *P. pusillus* and *P. berchtoldii*. The data are presented as numbers of remains per 100 cm^3 of wet sediment and are illustrated in a series of summary stratigraphic plots showing change in abundance of the major taxa through time, produced using C2 software (Juggins, 2003). The data were entered into Excel spreadsheets and are included as tables in Appendix 2. Where possible the findings are compared with historical plant survey data for the study sites.

Additionally, for the Tatton Mere sediment core, where charophyte oospores were abundant, a new identification system will be applied to the data. This system has recently been developed as part of a NERC funded project by ENSIS-ECRC that determines the provenance of the fossil oospores to species or sub-group level (Davidson *et al*., in prep.). This technique is currently being refined and the results will be incorporated into the final report. It is anticipated that the system will expand the potential of palaeolimnology for inferring submerged vegetation histories in lakes and the impact of enrichment on the plant communities (e.g. Bennion *et al*., 2009).

2.6 Application of macrophyte-nutrient models

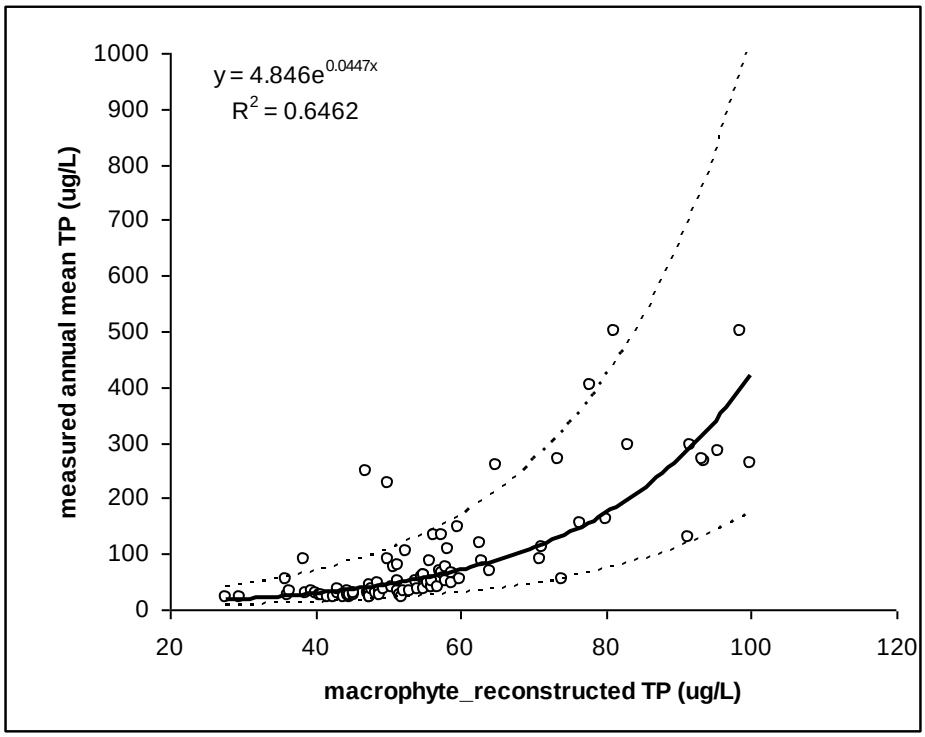
In addition to the diatom-based nutrient history, the collection of plant macrofossil remains allows for the application of modern plant-based training sets, developed as part of the LEAFPACS project (Willby *et al*., 2009), to the historical data. The use of multiple proxies for the prediction of TP helps to strengthen the certainty of the modelled historical data and increases the likelihood of determining accurate targets for both TP concentrations and aquatic macrophyte assemblages within these meres. Phosphorus (as TP) was hindcast by applying contemporary measurements of TP optima for macrophytes in 1600 lakes in central and NW Europe to the macrofossil data. To undertake this hindcasting the TP optima were weighted by the macrofossil counts of the taxa present. An additional weighting factor of 1, 0.1 or 0.01 was also applied to reflect the type of macrofossil or the reproductive output of different taxa, and their probability of occurring in the macrofossil record, since this probability may be disproportionate to their cover in the established vegetation. Thus, for example, entire *Nymphaea alba* seeds were given a weighting of 1, fragments of *Nymphaea alba* seeds carried a weighting of 0.1 (since they will be naturally more abundant), while nymphaeid trichosclereids (of which there are potentially thousands per leaf)

carried a weighting of 0.01. Of several different methods for calculating a macrophyte-inferred TP based on macrofossils, this method produced the best relationship with contemporary nutrient concentrations.

Macrophyte-inferred TP merely allows a measure of likely relative change in TP. Its relationship to actual TP concentrations will vary depending on the context in which the model is applied. However, for the purposes of setting targets, information on real TP concentrations is required. Therefore present day measured TP concentrations in the studied meres were compared with the values predicted for these same meres, based on their contemporary vegetation, where the macrophyte-inferred TP is derived from a cover weighted mean TP optima of the taxa recorded.

Furthermore, the relationship between observed and macrophyte-inferred TP concentrations across a wider range of meres (n = 20) for which macrophyte survey data are available was assessed in order to correct any systematic bias in TP estimates. This approach is necessary to correct for biases associated with the application of optima from large pan-European, multi-lake type datasets to specific situations. Hence a locally calibrated model was used to convert macrophyte-inferred TP to realistic concentrations in high alkalinity lakes such as the meres (Figure 1). To provide a sensible anchor at the low end of the nutrient gradient (30-50 µg TP L^{-1}) the model was supplemented using data from 70 high alkalinity shallow lakes in England, Wales and Northern Ireland with measured TP and contemporary aquatic vegetation similar to historical accounts and records of the vegetation of the meres.

Figure 1 Locally calibrated model for converting macrophyte-inferred TP concentrations to realistic TP concentrations in the meres



Dashed lines indicate 90% confidence limits. Note that sites at left hand end are comparable high alkalinity shallow lakes in England, Wales and Northern Ireland with measured TP and contemporary vegetation data. These sites are necessary to anchor the model at low TP concentrations and allow reconstruction of TP in the meres from eighteenth century aquatic plant records.

The model shown in Figure 1 will generate reasonable predictions of TP in average lakes, within confidence limits that are relatively large in absolute terms at the upper end of the range. However, it is well established that the meres are not average lakes. The application of this model to data from 20 well studied meres in Shropshire and Cheshire confirms that the model performs well in half the cases (predicted concentrations within ~25% of measured concentrations). However, some lakes fall very close to the extremities of the model, and indeed for several lakes, realistic predictions are not possible (Table 2). For the meres in the present study, the mean values from the locally calibrated model give a good match to the measured annual mean TP concentrations of the last decade.

Table 2 Comparison of measured and predicted TP concentrations in 20 well monitored meres, using a locally calibrated model

	measured annual mean TP (ug/L)	LMNI	macrophyte-inferred TP	calibrated			ratio calibrated:measured		
				mean	L 90CL	U 90CL	mean	L 90CL	U 90CL
Aqualate Mere	264	7.25	100	421	173	1018	1.60	**0.65**	3.86
Berrington Pool	113	6.39	70	**113**	47	271	**1.00**	0.41	2.39
Betley Mere	501	7.39	98	**395**	162	955	**0.79**	0.32	1.90
Betton Pool	89	6.77	73	128	53	307	1.44	0.60	3.46
Bomere Pool	69	6.00	64	**85**	35	204	**1.24**	0.52	2.96
Cole Mere	271	7.10	72	123	51	**296**	0.46	0.19	1.09
Comber Mere	266	7.15	94	**317**	130	766	1.19	**0.49**	2.88
Cop Mere	271	7.47	93	313	129	754	1.15	0.47	2.78
Crose Mere	131	7.02	81	**178**	73	426	1.36	**0.56**	3.26
Fenemere	499	6.83	67	98	41	235	0.20	0.08	0.47
Hatch Mere	85	6.51	64	**83**	35	199	0.99	0.41	2.36
Oakmere	118	6.12	58	64	27	**153**	0.54	0.23	1.29
Oss Mere	285	7.15	94	**324**	133	780	**1.14**	0.47	2.74
Petty Pool	295	6.91	83	198	82	477	0.67	0.28	1.62
Quoisley Big Mere	402	6.56	71	115	47	274	0.28	0.12	**0.68**
Quoisley Little Mere	259	6.92	65	88	36	**210**	0.34	0.14	**0.81**
Rostherne Mere	161	6.76	80	**174**	72	417	**1.08**	0.45	2.59
Tabley Mere	293	7.29	87	**241**	99	580	**0.82**	0.34	1.98
Tatton Mere	154	7.16	76	**147**	61	353	**0.95**	0.39	2.29
The Mere, Mere	53	6.65	72	121	**50**	289	2.29	**0.95**	5.49

Grey cells are used to denote those meres where the mean calibrated and measured concentrations show good agreement. For four sites highlighted in the two right hand columns the calibrated model poorly represents the observed concentrations which lie closer to the extremities of the model than its central tendency.

Total recovery of macrofossils of aquatic and wetland plants from the cores in the current study was relatively good in all cases, although the number of taxa recorded was comparatively poor, especially in Melchett Mere, with totals of 7, 28 and 12 taxa for Melchett, Tatton and Comber Mere, respectively, and most specimens could only be determined to family or genus level. Given that there are significant within-genus variations in nutrient affinity in many aquatic plants this constrains our ability to accurately reconstruct fertility for these sites, while the limited number of taxa recorded in any given section (median = 4, range = 1-12) must further reduce confidence in any predictions. Analysis of pollen in sediment cores may provide some additional species and assist in the determination of some macrofossils but it seems doubtful that the picture would be markedly different.

A complementary approach to the use of the macrofossil record for reconstruction is to supplement historical records of aquatic plants derived from archived observations and herbarium specimens. Unfortunately, the meres in question have a very poor historical record until the 1960s (Lockton *et al*., 2001), and the handful of eighteenth century aquatic plant records for the Tatton Park Estate cannot be definitively associated with its meres. The paucity of the historical record may reflect a historic lack of botanical interest (e.g. in terms of species richness or numbers of rarities) at the present sites when compared to other nearby meres which were well studied as far back as the early 1800s, or simply overshadowing by other larger or more accessible meres in the vicinity. An additional possibility in the case of the Tatton Meres is that because they formed progressively through subsidence of underlying salt deposits they are too young to have attracted earlier botanical recording effort. Thus, to an extent, the macrofossil and historical record are consistent in suggesting that the earlier aquatic vegetation of these sites was somewhat unremarkable in comparison to other meres.

In the absence of a good historical record from the sites in question one option is to use a spatial analogue approach, taking data from better recorded meres in the local area and using this to create a proxy for the under-recorded sites. Inference of the historical vegetation at the study sites is necessary to achieve an estimate of baseline TP concentrations which can provide an independent check on reconstructions based on macrofossils alone. This was attempted in this study by using historical data from the mid-1800s collated by Genevieve Madgwick (2010) from County Floras and herbarium specimens. Thus for Tatton and Melchett Meres we used historical data for Rostherne Mere, Budworth Mere, Mere Mere, Pick Mere and Tabley Mere. For Comber Mere, there were fewer well recorded sites in the immediate vicinity but adequate data were available for Blake Mere, Oss Mere and Quoisley Meres. The data used in this exercise are presented in Appendix 4.

2.7 Cladocera analysis

Cladocera are microscopic crustaceans (zooplankton) and are represented in lake sediments by a variety of body parts. They can be used to infer changes in fish population density and shifts in habitat structure (i.e. macrophytes) (e.g. Jeppesen *et al*., 1996, 2001; Davidson *et al*., 2007). They are particularly valuable in the context of this project in that they can be used to infer changes in macrophyte density with enrichment (e.g. Davidson *et al*., 2010). Given their intermediate and important position in the food-web the Cladocera data can complement the diatom and macrofossil records.

Cladocera analysis was carried out on approximately ten samples from each of the open water cores. The selected sub-samples were prepared using an adaptation of the standard sub-fossil Cladocera preparation technique (Korhola & Rautio, 2001). This method is based on that currently employed by colleagues working on Danish lakes (Jeppesen *et al*., 1996; Jeppesen, 1998). For each sample at least 5 cm^3 of sediment was heated in a deflocculating agent (10% potassium hydroxide, KOH) and sieved at 150 µm and 50 µm. The retents of the two sieves were then washed into separate pots and safranin stain was added. A sub-sample (of known volume) was screened with a compound microscope and the chitinous remains of the Cladocera were identified with reference to Flössner (1972), Frey (1958, 1959) and Alonso (1996). Carapaces, head-shields and post-abdomens were recorded separately. All Cladocera data are expressed as percentage relative abundance. The data were entered into Excel spreadsheets and are included as tables in Appendix 3.

2.8 Pigment analysis

Pigments of photosynthetic organisms including chlorophylls (Chls), carotenoids, photoprotective compounds and their derivatives are common in the sediments of aquatic environments (McGowan, 2007). They are produced by algae, phototrophic bacteria and aquatic plants and may also be present in detritus from terrestrial or resuspended material and in some invertebrate animals. Soft-bodied, morphological remains often decay in sediments and in such cases, biochemical fossils such as pigments may be the only signatures left behind. Pigments can be used to estimate past primary production in aquatic systems, and because many pigments show a degree of taxonomic specificity, they can provide information about past communities of algae or photosynthetic bacteria (e.g. McGowan *et al*., 2005).

Pigment analysis was carried out on selected samples from the open water cores in the pigment analytical facility at the University of Nottingham under the supervision of Dr S. McGowan. Pigments were quantitatively extracted in an acetone: methanol: water (80:15:5) mixture. The extracts were left overnight at -20 ºC, filtered with a PTFE 0.2 µm filter and dried down under nitrogen gas. A known quantity was re-dissolved into an injection solution of a 70:25:5 mixture of acetone, ion-pairing reagent (IPR; 0.75g of tetra butyl ammonium acetate and 7.7g of ammonium acetate in 100ml water) and methanol and injected into the HPLC unit. Pigment extracts were separated in an Agilent 1200 series separation module with quaternary pump. The mobile phase consisted of Solvent A (80:20 methanol: 0.5 M ammonium acetate), solvent B (9:1 acetonitrile: water) and solvent C (ethyl acetate) with the stationary phase consisting of a Thermo Scientific ODS Hypersil column (205 x 4.6 mm; 5 µm particle size). Eluted pigments passed through a photo-diode array detector and UV-visible spectral characteristics were scanned at between 350-750 nm. Peak areas were calibrated to commercial standards (DHI, Denmark). Quantification was based on scanning peak areas at 435nm and calibrating to a set of commercial standards (DHI Denmark). Pigment concentrations are reported as molecular weights of pigments per unit weight (in sediments).

Pigments detected in the meres sediments included fucoxanthin and diatoxanthin (siliceous algae), alloxanthin (cryptophytes), lutein, chlorophyll *b,* pheophytin *b* (chlorophytes or higher plants), zeaxanthin, canthaxanthin, echinenone (cyanobacteria), chlorophyll *a* and β-carotene (all algae and higher plants), and pheophytin *a* and Chl *a*' (breakdown products of Chl *a*).

2.9 Data analysis

Summary statistics of the biological data (diatoms, Cladocera, plant macrofossils) were calculated for each sample in the cores including the number of taxa observed and the Hill's N2 diversity score (Hill & Gauch, 1980). The results of the biological analyses were plotted as stratigraphic diagrams using C2 (Juggins, 2003). Cluster analysis was performed on the core data to identify the major zones in the biological records using CONISS (Grimm, 1987), implemented by TGView version 2.0.2 (Grimm, 2004) or ZONE v.1.2 (Juggins, 1991). CONISS is a program for stratigraphically constrained cluster analysis by the method of incremental sum of squares and ZONE is an MS-DOS program which employs a variety of constrained clustering techniques. Zones are illustrated on the stratigraphic plots for each biological group in order to facilitate description of the major compositional changes.

The degree of floristic change in the diatom assemblages and faunistic change in the Cladocera asssemblages between the bottom sample and every other sample in each core was assessed using the squared chord distance (SCD) dissimilarity coefficient (Overpeck *et al*., 1985) implemented in C2 (Juggins, 2003). This is preferred to other dissimilarity measures as it maximises the signal to noise ratio, it performs well with percentage data and has sound mathematical properties (Overpeck *et al*., 1985). The scores range from 0 to 2 whereby 0 indicates that two samples are exactly the same and 2 that they are completely different. Scores less than 0.29, 0.39, 0.48 and 0.58 indicate insignificant change at the 1st, 2.5th, 5th and 10th percentile, respectively (Simpson, 2005; Simpson *et al*., 2005). It is advised that the 2.5th percentile (score <0.39) is used here to define sites with low change between the bottom and every other sample. The SCD scores were not calculated for the macrofossil assemblages owing to the difficulty of applying this technique to abundance data, especially where the amount of the identifiable remains varies between plant taxa.

Indirect ordination techniques (principal components analysis – PCA) (ter Braak & Prentice, 1988) were used to analyse the variance downcore within the diatom and Cladocera assemblages using C2 (Juggins, 2003). The technique summarises the main changes in the data and helps to identify zones of change within complex species-rich data sets. The sample scores for PCA axis 1 are given. Where scores between two neighbouring samples in the core differ markedly this indicates that the assemblages have undergone substantial change between these two points in the core. The scores are also plotted in the stratigraphic diagrams to illustrate the timing of any shifts and whether these were gradual or abrupt. The PCA scores were not calculated for the macrofossil assemblages owing to the difficulty of applying this technique to abundance data (see above).

3. MELCHETT MERE

3.1 Core description

A tapper core, 0.48 m in length (MELC3), was collected from Melchett Mere on 15-Feb-10 in 11.6 m water depth, in the deepest part of the basin. The upper 5 cm of the core was slightly disturbed and flocculant and, therefore, this was taken as an amalgamated surface sample.

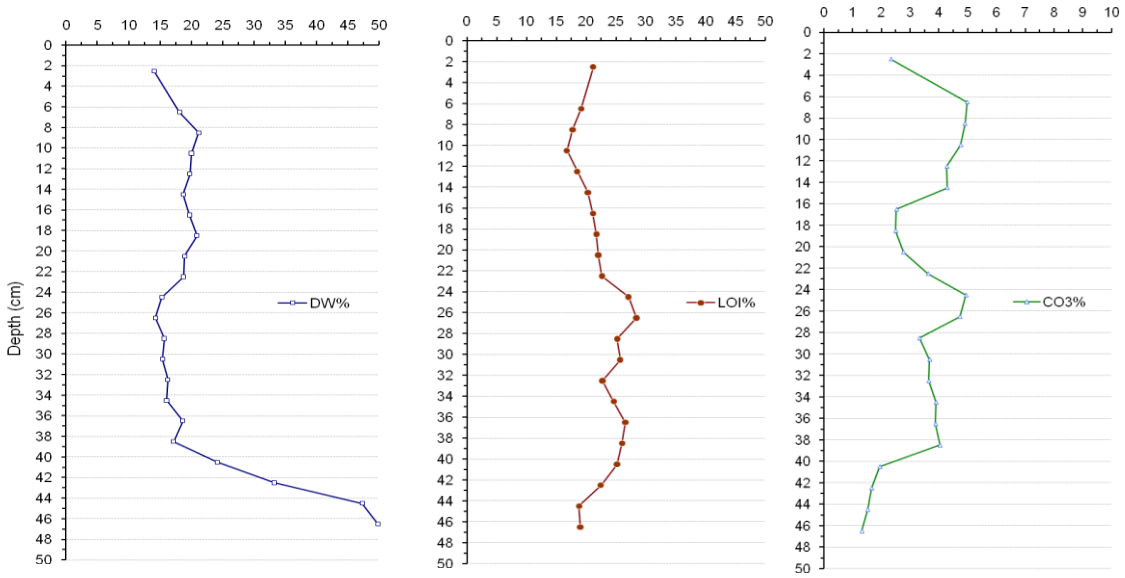
The core had two distinct horizons (Figure 2). The upper 42 cm of the core was dark brown in colour and appeared to be relatively organic. The section from 42 cm was lighter brown in colour and was a stiffer soil-like material containing roots and stones.

The different nature of the core section below 42 cm from that above this depth was also reflected in the stratigraphic data (Figure 3). The %DW values were > 30% below 42 cm, reaching a maximum of 50% at the core base, compared with values of ~20% above 42 cm, indicating much denser material in the lower 6 cm of the core than in the rest of the record. Organic matter and carbonate content were also relatively lower in the bottom-most samples of the core. The core was relatively organic throughout with LOI% ranging from ~15-25%, and carbonate content was low, fluctuating between 1-5%. The most organic and carbonate-rich section of the core was from 25-27 cm.

Figure 2 Sediment core stratigraphy of MELC3

Depth (cm)	Sediment colour
0-42	Dark brown
42-48	Light brown

Figure 3 Percentage dry weight (DW), organic matter (LOI) and carbonate (CO_3) profiles of MELC3



3.2 Dating

The SCP concentrations for MELC3 from Melchett Mere are shown in Table 3 and Figure 4. A first presence of SCPs occurs at 43 – 44 cm. Concentrations increase slowly to 22 – 23 cm and then more rapidly to ~10 – 11 cm. SCP concentrations peak in the 8 – 9 cm sample at around 17400 gDM^{-1} but concentrations in the uppermost sample (0 – 5 cm) are also high (16400 gDM^{-1}). It is unfortunate that the sample resolution in the upper part of this core is so coarse (0 – 5 cm was an amalgamated sample) as this greatly reduces interpretation of this part of the profile. We can only assume that the SCP concentration in the 0 – 5 cm sample is a mean for this whole 5 cm section. However, this assumption leads to uncertainty as the SCP concentration in this sample is high and it is, therefore, unclear whether the SCP concentration peak (usually an obvious feature) is that observed at 8 – 9 cm or whether it falls within the 0 – 5 cm section. Assuming the former, the mean sediment accumulation rate for the uppermost 8.5 cm of the core would be 0.265 cm yr^{-1} (values range from 0.22 – 0.31 cm yr^{-1}).

The rapid increase in SCP concentration associated with the increase in electricity demand after the Second World War and usually ascribed to ~1950 is not as apparent as in most cores. However, the profile suggests that it is most likely to be at around 22 cm depth. If this is so, then it would suggest a mean rate of sediment accumulation between 1950 and 1978 of 0.48 cm yr^{-1}, considerably higher than the post-1978 period. A depth of 22 cm for the rapid increase is therefore incompatible with a constant sediment accumulation rate if the SCP concentration peak is really at 8 – 9cm. Hence, either the allocation of the SCP peak and / or rapid increase are incorrect or the sediment accumulation rate has declined considerably in the more recent period.

The start of the SCP record is usually ascribed to the mid-19th century. However, in rapidly accumulating sediment, the SCP concentration can be diluted to below the analytical limit of detection such that the SCP profile is truncated. Assuming we have a complete profile, and that 1950 is at around 22 cm and 1850 is at around 46 cm, then the mean sediment accumulation rate for the period 1850-1950 would be ~0.24 cm yr^{-1}, similar to that suggested for the uppermost section of the core and lower than the 1950 – 1978 period. If this is true, then the sediment accumulation rate of Melchett Mere may have been relatively steady over

the last century or more, interrupted by a period of increased sedimentation rate between the 1950s and the mid-1970s. This is, however, highly speculative.

In summary, it is difficult to ascribe dates to the MELC3 core with any confidence and this is further hampered by the uncertainty over the sediment record in the 0 – 5 cm section and the unusual origin of the lake. What we can say is that sediment above 44 cm was deposited within the last 160 years and that 1950 ± 10 is most likely to be at around 22 cm.

Figure 4 SCP profile for MELC3

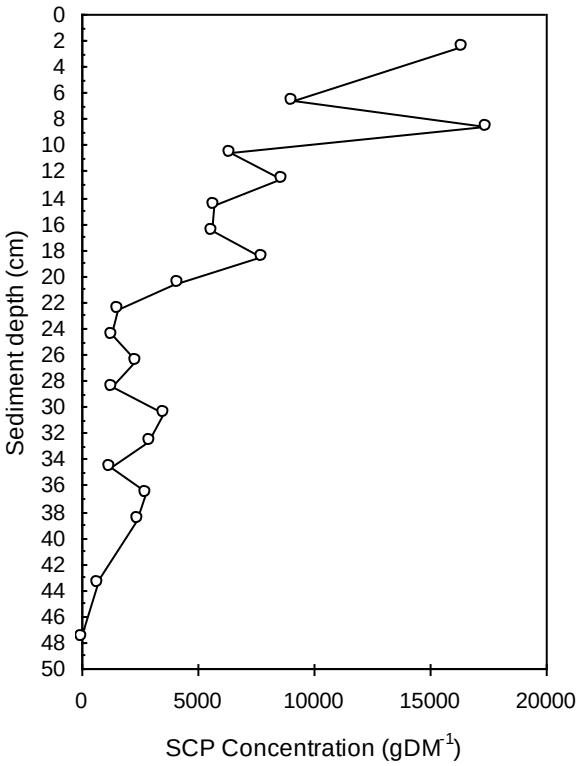


Table 3 SCP concentrations for MELC3

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
2.5	16385	3423
6.5	9078	2158
8.5	17380	3110
10.5	6346	1795
12.5	8620	1938
14.5	5653	1239
16.5	5592	1329
18.5	7766	1746
20.5	4119	1346
22.5	1556	682
24.5	1290	632
26.5	2351	1030
28.5	1278	885
30.5	3523	1305
32.5	2965	1453
34.5	1167	660
36.5	2772	1109
38.5	2397	959
43.5	685	671
47.5	0	0

3.3 Diatom analysis

Ten samples were analysed for diatoms in the MELC3 core (Table 4). Preservation of the siliceous valves was reasonable in the upper 10 cm of the core and between 25 – 40 cm, but samples between 10 -25 cm showed significant dissolution and analysis was not possible. Below 40 cm, the microscopic structure of the samples was very different, consisting of larger, soil-like particles rather than typical lake sediments and with only very few diatoms present. A total of 83 diatom taxa were observed in the core with between ~30-50 taxa recorded per sample, and the results for the major taxa are shown in Figure 5.

There was marked change in the diatom assemblage during the period represented by the core and cluster analysis separated the upper section of the core from the samples analysed from below the section with poor preservation. A total of four separate zones are therefore described: Zone 1, from the core base to 42 cm (date unknown), Zone 2 from ~41 to ~22 cm (Lake formation (?) - ~1950), Zone 3 from ~22 - ~12 cm (~1950 - 1975) and Zone 4 from ~12 cm to the surface (~1975 to present).

Zone 1 had almost no diatoms present and the particle size of the sediments was significantly larger than that of the upper zones. The few diatoms that were noted were

Pinnularia spp. which are often associated with damp soils and bogs, suggesting this zone pre-dated the lake formation.

Zone 2 samples were relatively diverse (N2 > 10) and comprised largely of non-planktonic taxa (~80% of the total assemblage) associated with relatively unproductive waters, particularly *Achnanthidium minutissimum*, *Eunotia* spp., *Fragilaria tenera* and *F. famelica.*

Zone 3 represents a period of poor diatom preservation.

In Zone 4 the proportion of planktonic taxa increases from 45 – 80% with *Aulacoseira ambigua, A. granulata* and *Asterionella formosa* dominating the plankton. Another notable difference between the zones was the absence of *Eunotia* spp. in the upper zone, which instead had higher numbers of small benthic '*Fragilaria'* species present. The hiatus in the core is unfortunate, but the results show a shift from less productive benthic taxa pre-1950 to an increasingly plankton dominated assemblage from ~1975 to the present day.

The diatom results appear to indicate a relatively stable period in the early part of the mere's history with only subtle species shifts prior to ~1950. After ~1950, the environment shifted towards conditions less favourable to diatom preservation; often this is due to more alkaline water chemistry. By the time diatom preservation improves again (post ~1975) the increasingly planktonic assemblage is one more typical of slightly enriched conditions which appear to have prevailed to the present day. The change in the diatom assemblages between Zones 2 and 4 are recorded by the PCA axis 1 scores which show a marked decrease in the upper zone. The SCD scores are high (>1.0) in the upper zone reflecting the difference of the more recent diatom assemblages from those at the base of the core.

The diatom-inferred TP (DI-TP) reconstruction suggests that TP concentrations were relatively stable prior to ~1950 and in the region of 40-50 µg L^{-1}. In the upper samples, the TP values can be seen to increase to 80- 90 µg L^{-1} if using WA-PLS component 1, or slightly less (~ 60 µg L^{-1}) if using the WA-PLS component 2 model. We do not have current TP data for Melchett Mere with which to compare the inferred model values, but Moss *et al.* (1992) reported an annual mean TP of 32 µg L^{-1} and limited Environment Agency data from 2000 recorded TP values in the range 13-43 µg $L^{-1.}$ It would appear, therefore, that the model overestimates TP concentrations for this site.

In summary, the diatom assemblages of MELC3 exhibited a period of relatively stability prior to ~1950, with a benthic flora typical of shallow, clear-water sites of moderate alkalinity and nutrient status. Conditions then changed, during which diatom preservation was poor, followed by a more recent phase (post ~1975) typified by an increase in planktonic, nutrient-tolerant taxa, which now dominate the diatom flora.

Table 4 Results of the diatom analysis on MELC3

Depth (cm)	No. of taxa	N2	DI-TP (1) µg L^{-1}	DI-TP (2) µg L^{-1}	SCD	PCA axis 1 scores
0	28	4.64	89	62	1.12	-0.94
5	36	4.47	82	53	1.13	-1.03
10	35	6.05	81	57	1.11	-0.74
25	45	10.74	50	51	0.39	1.16
30	43	13.10	51	49	0.26	0.84
40	50	13.05	44	41		0.71

3.4 Macrofossil analysis

3.4.1 Plant macrofossils

Ten samples were analysed for plant macrofossil remains in the MELC3 core (Table 5). A total of seven taxa were observed in the core and a summary diagram for the major taxa is presented in Figure 6. Macrofossil remains were relatively sparse within the Melchett Mere core and aquatic species diversity was low throughout (Table 5). The cluster analysis identified three zones in the plant macrofossil record. Approximate dates of the changes are given based on the SCP dating results.

Zone 1 (48-42 cm, ~pre-1850-1880) comprised only one sample which was dominated by *Chara* oospores ('oval' type) at a relatively low density of 84 oospores per 100 cm^3.

In Zone 2 (42-5 cm, ~1880-2000) the aquatic plant diversity rose slightly with an increase in *Potamogeton* fine-leaved remains, *Potamogeton* seeds, *Nymphaea alba* seed fragments and *Callitriche* seeds. The abundance of *Chara* oospores ('oval' type) decreased during this period and disappeared from the record after the 28 cm sample (~1930).

Zone 3 (5-0 cm, ~2000-2010) comprised only one bulk sample and was dominated by *Potamogeton berchtoldii/ pusillis* leaf tips.

Table 5 Results of the plant macrofossil analysis on MELC3

Depth (cm)	No. of taxa	N2
1	3	2.03
8	1	1
15	2	1.6
18	3	2.18
21	5	2.24
25	3	2.57
28	3	2.10
35	1	1
38	2	1.32
45	3	1.16

3.4.2 Zooplankton ephippia

The cluster analysis identified two zones in the ephippia record (Figure 7).

Zone 1 (45-20 cm, ~1850-1950) samples were composed of *Simocephalus* spp. with low numbers of *Daphnia hyalina* and *Ceriodaphnia.*

In Zone 2 (20-0 cm, ~1950-2010) numbers of *Daphnia hyalina* and *Ceriodaphnia* increased whilst those of *Simocephalus spp.* decreased. The most abundant remains were found in the upper two samples (representing ~1980 to the present day) with increases in *Daphnia hyalina, Ceriodaphnia* and *Daphnia pulex.*

3.5 Cladocera analysis

Seven samples were analysed for chitinous cladoceran remains in the MELC3 core (Table 6). A total of 15 taxa were observed in the core and a summary diagram for the major taxa is presented in Figure 8. Three zones were identified by cluster analysis and approximate dates of the changes are given based on the SCP dating results.

Zone 1 (48-35 cm, ~pre-1850-1900) was particularly species poor, and was dominated by *Bosmina longirostris* (85-92%) with *Chydorus sphaericus* and *Alona quadrangularis* the only other notable taxa. The SCD scores were low indicating little change between the bottom sample and the other sample in the zone.

Zone 2 (35-12.5 cm, ~1900-1975) saw an increase in species diversity with low numbers of benthic taxa (i.e. commonly found amongst mud at bottom of ponds) such as *Leydigia leydigii, Alona guttata* and *Pleuroxus uncinatus* present towards the top of the zone, post ~1950. The relative abundance of *B. longirostris* declined slightly while that of the slightly larger, open-water species *Bosmina coregoni* increased. The SCD and PCA axis 1 scores increased towards the top of this zone reflecting these floristic changes.

In Zone 3 (12.5-0 cm, ~1975-2010) the relative proportions of *B. longirostris* and *B. coregoni* shift again, to increased numbers of the former and decreased numbers of the latter. The species composition is similar to that of Zone 2, except for an increase in *Daphnia hyalina/longispina* agg. chitinous remains, such as shell spines and post-abdomens. This is consistent with the increased numbers of *Daphnia* spp. observed in the ephippia data (see section 3.4.2). It should be noted that the top 5 cm of the core were merged in order to extract enough material for analysis. The low SCD scores (<0.4) reflect the dominance of *B. longirostris* throughout the core. There is a marked change in the PCA axis 1 scores at the Zone 2/3 boundary arising from the sharp decline in *B. coregoni*.

Table 6 Results of the Cladocera analysis on MELC3

Depth (cm)	No. of taxa	N2	SCD	PCA axis 1 scores
0	13	1.94	0.21	-0.04
10	13	1.59	0.14	-0.46
15	12	2.57	0.42	1.45
20	11	2.21	0.35	1.20
30	12	1.90	0.18	-0.06
40	10	1.37	0.04	-0.89
48	10	1.18		-1.20

3.6 Pigment analysis

Six samples were analysed for sedimentary pigments in the MELC3 core. A total of 11 chlorophylls and carotenoids were observed in the core and a summary diagram is presented in Figure 9. Pigment concentrations were moderate in this core and the presence of relatively labile fucoxanthin and Chls *a* and *b* indicate good preservation in the sediments. Three zones were identified by cluster analysis and approximate dates of the changes are given based on the SCP dating results.

Zone 1 (48-43 cm, ~pre-1850-1880) consisting of a single basal sample contained no pigments other than pheophytin *b*, a degradation product of chlorophytes or higher plants. This is consistent with inputs from either terrestrial or aquatic plants, indicating that this part of the core probably marks the origin of the lake and the conversion from terrestrial to aquatic habitat.

Zone 2 (43-14.5 cm, ~1880-1975) pigments increased in abundance relative to zone 1, and then most are maintained at intermediate and stable concentrations throughout the zone. This assemblage indicates the establishment of aquatic production. The exception to this pattern is pheophytin *b*, pheophytin *a* and β-carotene which increase ~1900, possibly related to changes in aquatic plant abundance.

In Zone 3 (14.5-0 cm, ~1975-2010) there is a marked increase in abundance of most pigments (except for pheophytin *b*), indicating an increase in aquatic production. The

increase in pigment abundance starts to occur in the sample at 10 cm depth and so is unlikely to be caused by degradation patterns because most degradation is usually confined to the uppermost centimetres of sediment. The very marked increases in labile fucoxanthin and Chls *a* and *b* of the uppermost sample may be partially driven by degradation however. Overall, the pigment assemblages in this zone indicate substantial increases in the production of siliceous algae, cryptophytes, chlorophytes and cyanobacteria.

3.7 Application of macrophyte-nutrient models

The macrofossil based reconstruction points to a virtual doubling in macrophyte-inferred TP over the depth of the core, with a pronounced spike at 18 cm (approximately 1960s) (Figure 10). In real terms, based on the locally calibrated model, this suggests a rise in TP concentrations from 37 (90 % confidence limits 15 – 88) to 194 (80 - 465) µg L^{-1}.

The macrofossil reconstruction for the core surface exhibits a good fit with the reconstruction based on the contemporary (2002) vegetation described in Lockton *et al.* (2001). As a reference point for the base of the core we used historical botanical records from the mid-1800s for a number of better recorded meres in the vicinity (Rostherne, Mere Mere, Tabley, Budworth and Pickmere), there being a virtual absence of historical records of aquatic plants definitively assignable to Melchett Mere until the 1970s. These combined approaches suggest a rise in macrophyte-inferred TP from 68 – 87 µg L^{-1} over the last ~150 years, equivalent to real term change rise in TP from 103 (43 – 246) to 237 (98 – 571) µg L^{-1}. The macrofossil reconstruction for the base of the core (46 cm) departs somewhat from the reconstruction based on the mid-1800s historical record archive for adjacent water bodies, but there is a good match between macrofossil and historical data for the depth range 22-38 cm and a similarly good correspondence between alternative sources of evidence for the prediction of contemporary fertility. The macrofossil record for the core base is rather sparse and contains only *Potamogeton berchtoldii/pusillus* leaf tips, *Sphagnum* and *Chara* oospores (oval type). The optima value applied to *Potamogeton berchtoldii/pusillus* leaf tips is based simply on the average of the optima of the two taxa but the appropriateness of this will vary depending on the relative amounts of these two species. Similarly, for *Chara* a generic optima is used in the reconstruction of TP, yet in reality the TP optima of individual *Chara* species ranges from 30 - 80 µg L^{-1}. Consequently, given these uncertainties, a baseline fertility of between 80 – 130 µg L^{-1} TP might be a sensible compromise for this site.

3.8 Discussion

The palaeoecological record of Melchett Mere appears to extend back to the formation of the lake. The section below 42 cm was comprised of a dense, soil-like material rather than organic lake mud (gyttja). The lowermost sample of the core contained very few diatoms and those present were mainly aerophyllous *Pinnularia* species, suggesting a wetland phase. Similarly the basal sample contained no pigments other than pheophytin *b*, indicating that inputs were from either terrestrial or aquatic plants. Plant macrofossil numbers were low with only small amounts of *Chara* oospores, *Carex* seeds and *Potamogeton berchtoldii/pusillus* leaf remains. Similarly zooplankton ephippia abundance was very low. The evidence, therefore, points to a wetland habitat at this time. Unfortunately, a robust chronology could not be established for the Melchett Mere core and thus the timing of the changes in the record cannot be established with any certainty. Nevertheless the SCP results suggest that the record extends back to at least ~1850. The existence of a wetland prior to 1900 is consistent with what is known of the lake origin as it is thought to have formed in the early 1900s by a large underground collapse, probably related to water erosion of the underlying Cheshire salt deposits. The early diatom assemblages of Melchett Mere, prior to ~1950, were comprised of largely non-planktonic taxa indicating a shallow water environment at that time. Several of these taxa (e.g. *Eunotia minor, Eunotia curvata*) are typically associated with

slightly acidic, unproductive waters which suggests that the site may have been a shallow peat-fen prior to formation of the deeper open water system that exists today. While pigment concentrations increased in abundance above 40 cm, indicating the establishment of aquatic production, they remained at intermediate values and were relatively stable until the mid-1900s.

The most striking changes in the core occurred from the mid-1900s.The diatom flora in the upper core was markedly different from that in the lower section, being dominated by planktonic taxa typically associated with alkaline, productive lakes. This indicates a major change in the habitat to one of deeper, open water. The assemblage is comprised of a range of species that occupy various periods of the growing season. For example, *Stephanodiscus parvus* and *Asterionella formosa* tend to appear in spring, while *Aulacoseira granulata* and *Aulacoseira ambigua* generally peak in the late summer to autumn months. This suggests that planktonic algae are present for much of the year. The species shifts result in a notable increase in DI-TP values from ~40 µg L^{-1} in the lower core to ~80 µg L^{-1} in the upper zone, signalling enrichment of the lake. The national target for TP for a lake of this type is an annual mean concentration of 50 µg L^{-1} and, therefore, the diatom model suggests that in the past concentrations were within this target but currently the lake exceeds this value. There were no measured TP data available at the time of reporting for comparison with the diatom model outputs although limited Environment Agency data from 2000 recorded TP values in the range 13-43 µg L^{-1} and Moss *et al.* (1992) reported an annual mean TP of 32 µg L^{-1}. If TP concentrations have remained at similar values to these over the last decade then it would appear that the model overestimates TP concentrations for this site.

The diatom data are supported by the zooplankton data which exhibit a major change since the mid-1900s with a marked increase in taxa associated with open water (*Ceriodaphnia* spp and *Daphnia hyalina* agg.) and a concomitant decline in *Simocephalus* spp. which is plant-associated. Most noteworthy is the striking increase in the large-bodied pelagic *Daphnia* species from ~1950 with very high numbers of ephippia in the recent sediments, indicating greater availability of planktonic algae as a food source. This accords with the rise of *Bosmina coregoni* since the mid-1900s seen in the chitinous record, an open-water species which also feeds on planktonic algae, although its subsequent decline from ~1970 is most likely due to competitive exclusion by *Daphnia*. Indeed the co-existence of *Daphnia* and *Bosmina longirostris* since ~1950 suggests that food is in plentiful supply. The zooplankton changes are, therefore, indicative of greater planktonic production and thus agree with the shift in the diatom data to a plankton dominated flora. A marked increase in abundance of most pigments in the upper core is also suggestive of enhanced aquatic production. In combination, these shifts signal enrichment of the lake from the mid-1900s with a consequent decrease in plant abundance.

Unfortunately it is not possible to assess changes in the plant community of the lake with any confidence owing to the fact that macrofossil analysis had to be carried out on a core collected from the deep basin of the site (~11 m) as intact marginal sediments could not be found. The paucity of remains in the deepwater core arises because plants are not growing *in situ* at the coring site. Those that were found in the record, largely *Potamogeton* remains, are likely to have rafted out to the deeper water from the littoral zone rather than to have been growing locally. The study shows that aquatic plants have always been present at the site but does not provide any reliable information on dynamics. The data suggest that there might have been a shift from *Chara* to *Potamogeton* taxa, which would be consistent with the eutrophication story, but given the problematic nature of this site for macrofossil analysis this interpretation should be treated with caution. According to the recent site condition report for the Tatton Meres SSSI (Natural England, 2008; Goldsmith, 2010) Melchett Mere has an extensive community of submerged macrophytes. Historical surveys carried out at the mere in 1979, 1989 and 2001 (collated by G. Madgwick) record several *Callitriche* spp, *Eleocharis acicularis, Myriophyllum spicatum, Potamogeton berchtoldii, Potamogeton pectinatus* and *Ranunculus circinatus* in all three years. *Elodea canadensis* was first recorded in 1989 and again in the 2001 survey, and *Zannichellia palustris* was recorded in the 2001 survey only.

Several of these taxa were present in the macrofossil record, namely *Callitriche* spp. and the fine-leaved *Potamogeton* taxa, but evidently the deepwater core under-represents plant diversity. In fact even in cores from shallow lakes, there is a tendency for some taxa to be poorly represented in the macrofossil record (e.g. Davidson *et al.,* 2005). *Nymphaea alba* remains were also found in the core, albeit in low numbers, and this is consistent with records of nymphaeids in the past by Lockton *et al.* (2001). However, current records confirm sparseness of nymphaeids at the site. A possible explanation for the decline in nymphaeids might be dieback resulting from exposure of the lake margins in severe drought years but local data are required to explore this further. It is noteworthy that Charophytes were not recorded in the previous plant surveys thereby indicating that they had been lost from the site some time prior to 1979. The arrival in 2001 of *Zannichellia palustris,* a species typically found in nutrient-rich waterbodies*,* is perhaps suggestive of increased nutrient production in the last decade. In spite of the problems associated with macrofossil analysis of the Melchett Mere core the macrophyte-inferred TP reconstruction concords with the general picture of enrichment as interpreted from the other proxies, exhibiting a marked increase over the period represented by the core.

In summary the early changes observed in the Melchett Mere sediment record are indicative of a deepening of the site during formation of the lake, and the changes since ~1950 are indicative of nutrient enrichment. Given the relatively low resolution of the analysis and a lack of detailed site history it is not possible to establish the causes of the observed ecological shifts to any greater degree at this stage. The unusual origin of the site makes it difficult to define reference conditions but, nevertheless, it can be concluded that there has been an increase in pelagic productivity since approximately the mid-1900s consistent with eutrophication.

Figure 5 Summary diatom diagram of Melchett Mere core, MELC3
(note that there are uncertainties surrounding the chronology and the lake is thought not to have formed until the early 1900s)

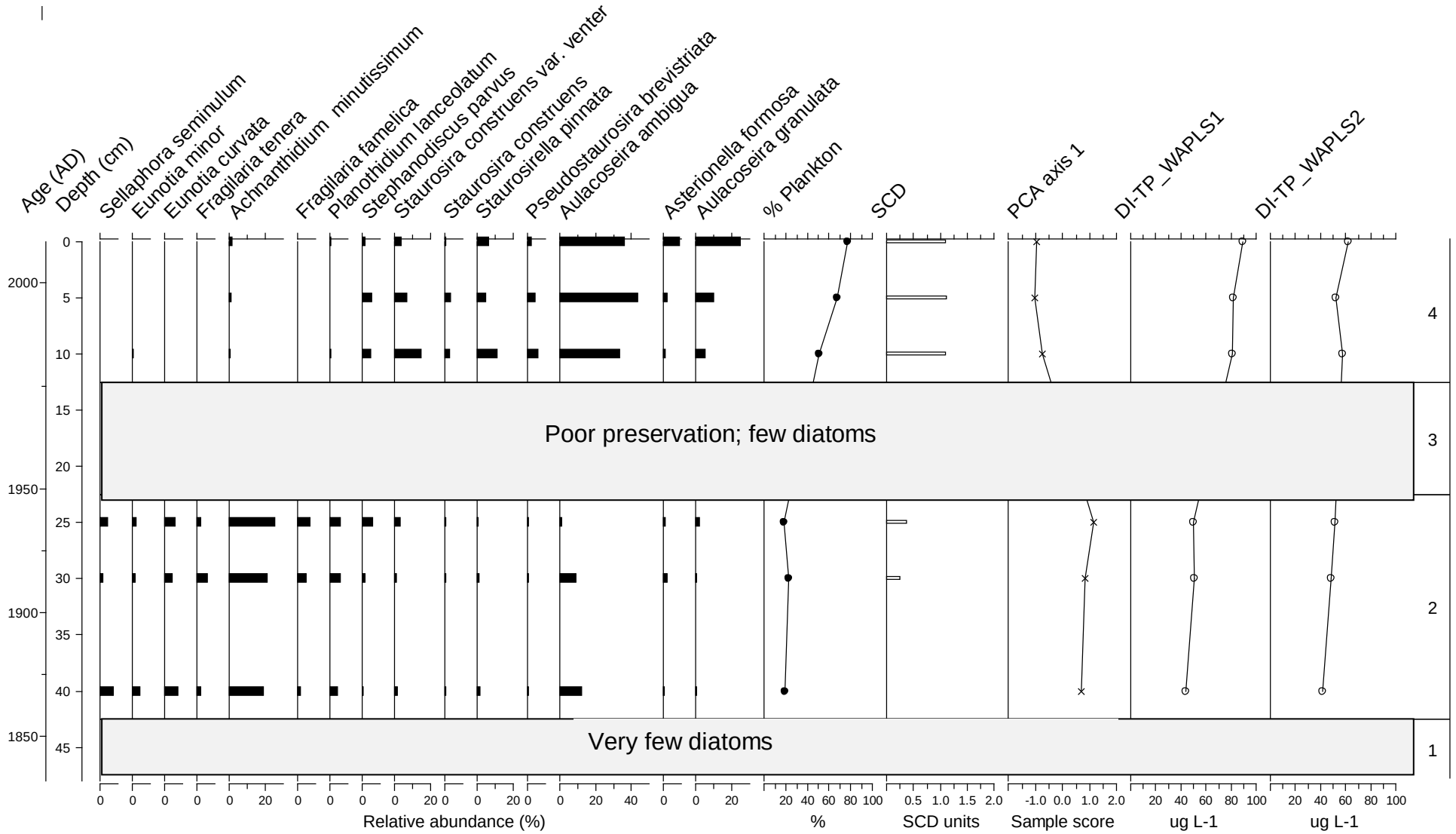


Figure 6 Summary plant macrofossil diagram of Melchett Mere core, MELC3
(note that there are uncertainties surrounding the chronology and the lake is thought not to have formed until the early 1900s)

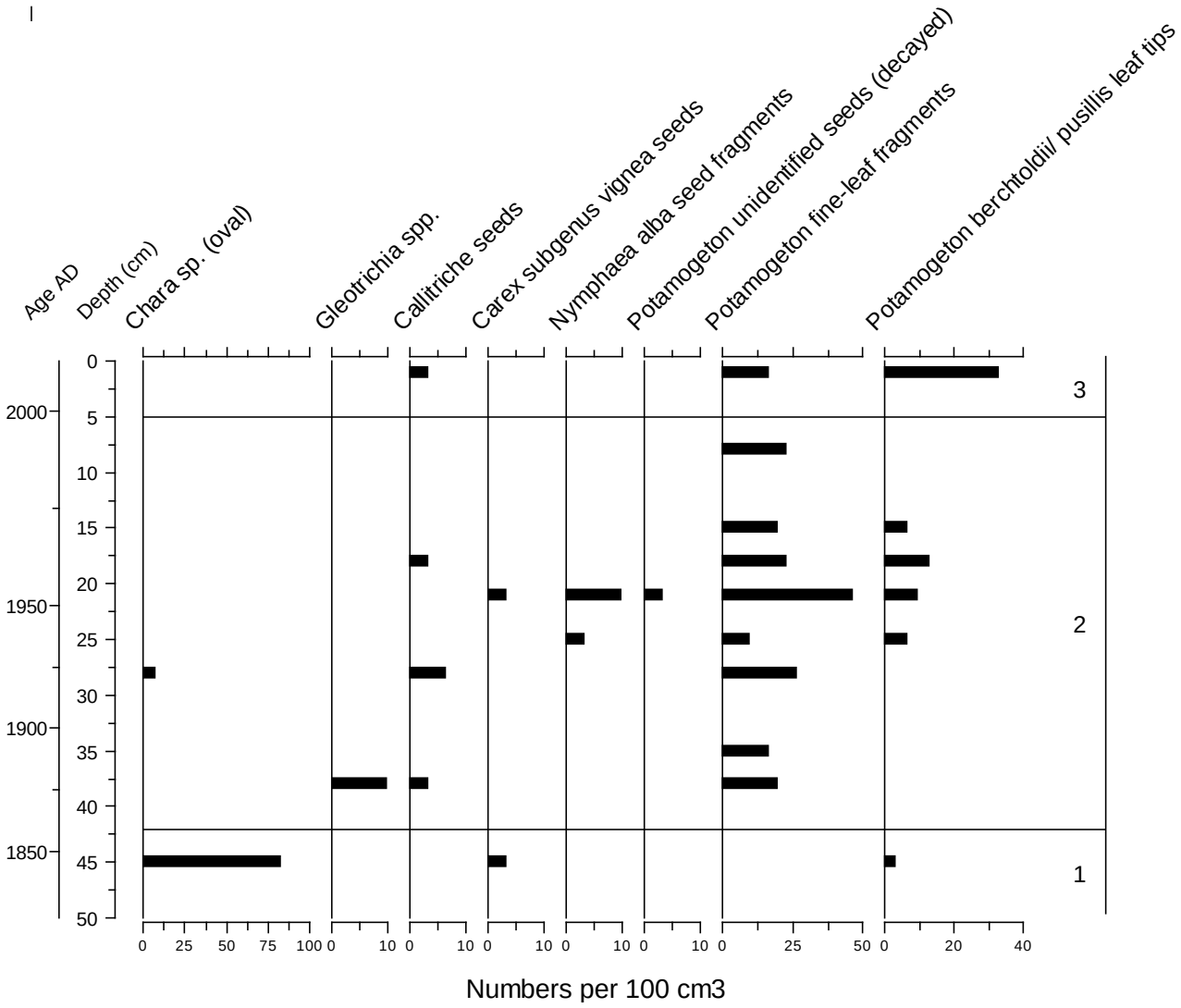


Figure 7 Summary zooplankton ephippia diagram of Melchett Mere core, MELC3
(note that there are uncertainties surrounding the chronology and the lake is thought not to have formed until the early 1900s)

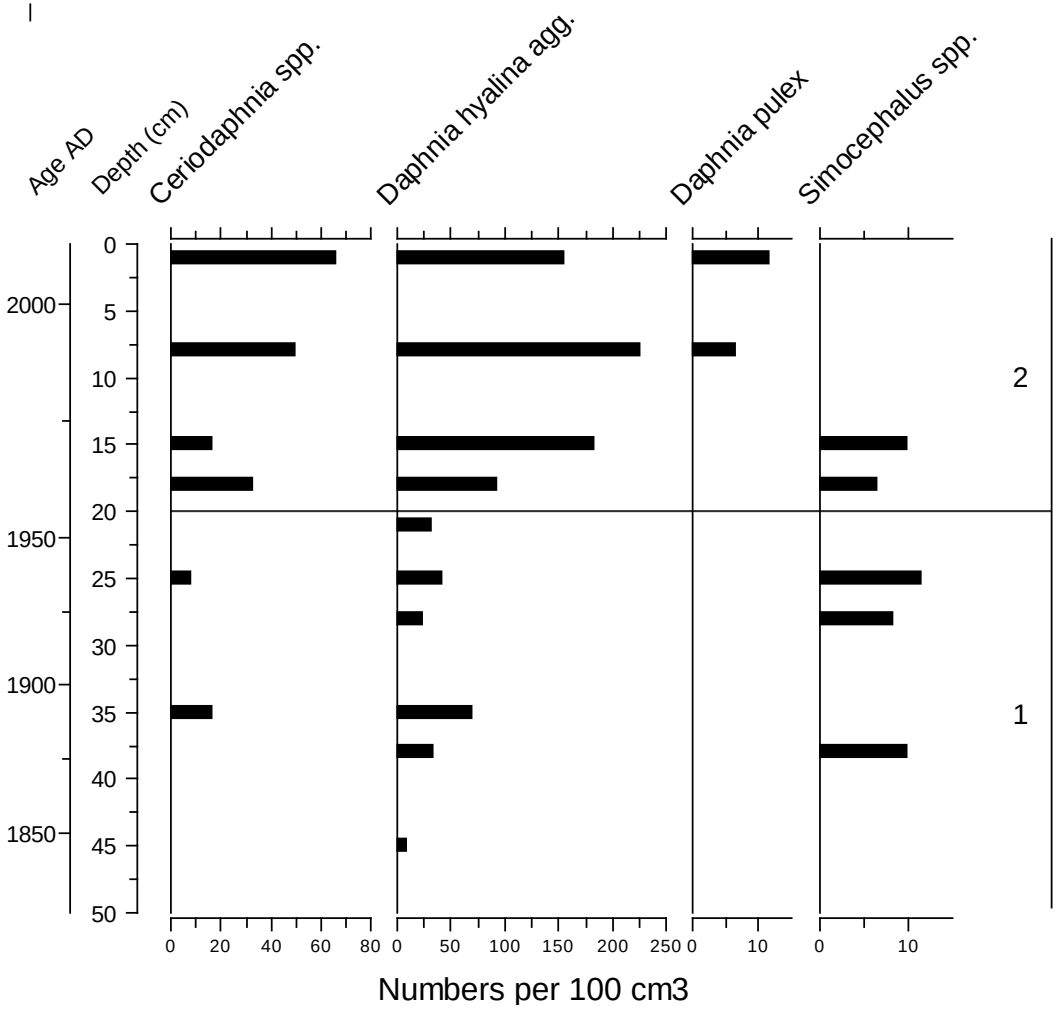


Figure 8 Summary Cladocera diagram of Melchett Mere core, MELC3
(note that there are uncertainties surrounding the chronology and the lake is thought not to have formed until the early 1900s)

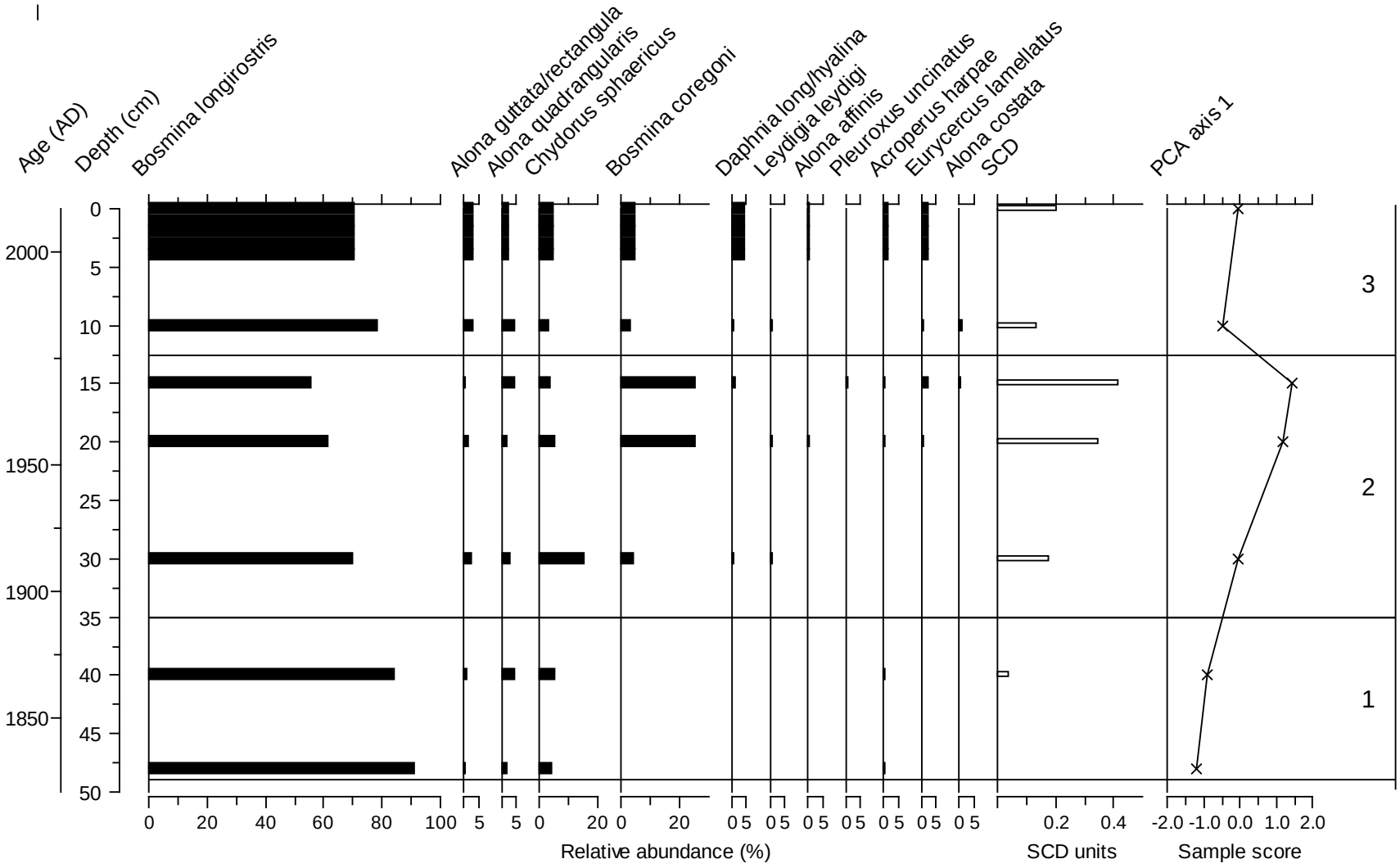


Figure 9 Summary pigment diagram of Melchett Mere core, MELC3

Concentrations in nanomoles per gram organic weight sediment; note variable scaling on the x axes
(note that there are uncertainties surrounding the chronology and the lake is thought not to have formed until the early 1900s)

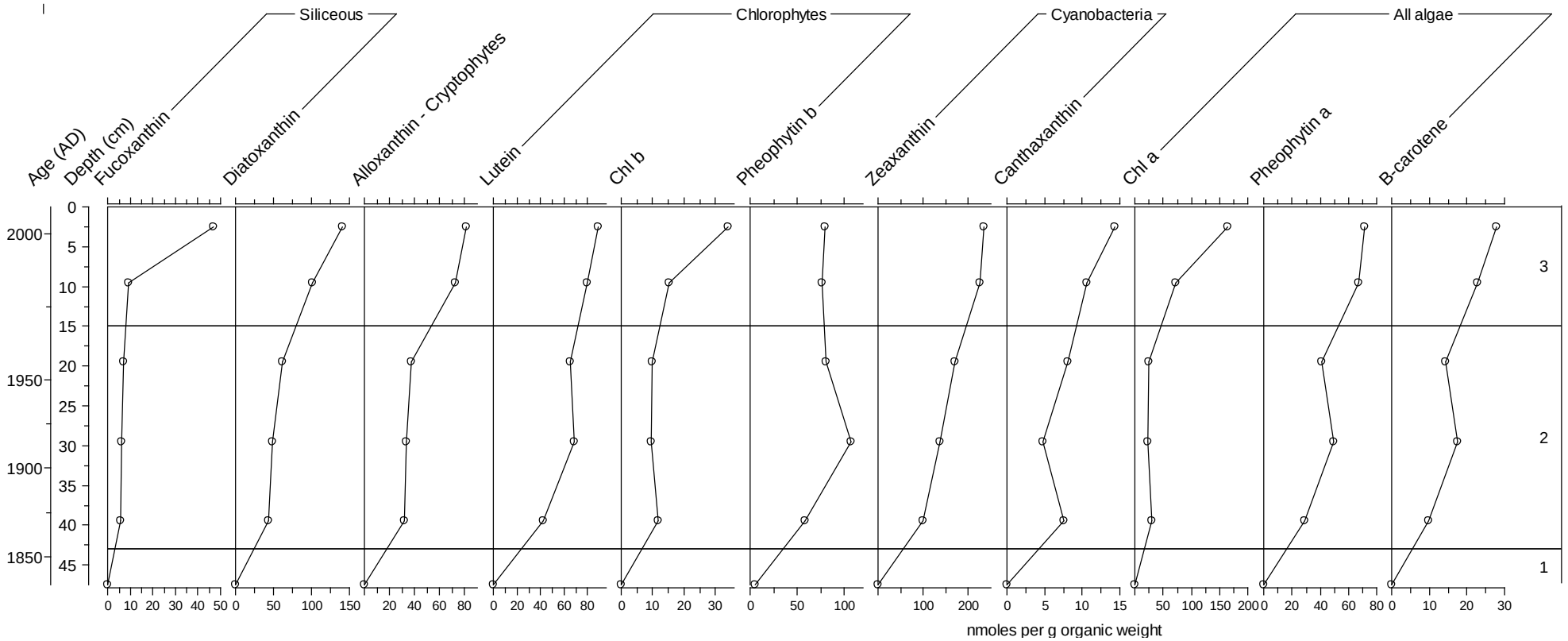
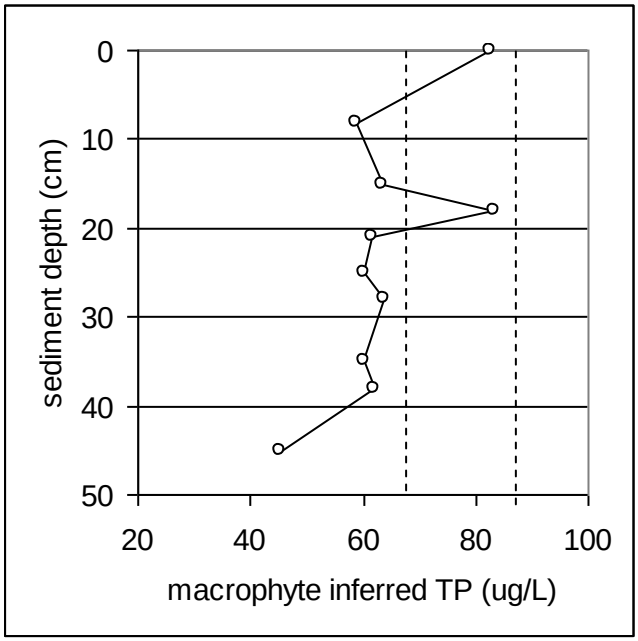


Figure 10 Macrophyte-inferred TP for Melchett Mere



Note: Points indicate macrofossil based reconstructions. Left hand dotted line indicates reconstructed mid-1800 TP using spatial analogue approach with historical record data from adjacent meres. Right hand line indicates reconstructed TP using contemporary vegetation.

4. TATTON MERE

4.1 Core description

A tapper core, 1.19 m in length (SCM41E), was collected from Tatton Mere on 16-Feb-10 in 11.6 m water depth, in the deepest part of the basin. The upper 2 cm of the core was slightly sloping and flocculant and, therefore, this was taken as an amalgamated surface sample.

The core was homogeneous and dark brown/black in colour throughout with no visible colour change (Figure 11). The core appeared to be organic and had no visible plant remains.

Figure 11 Sediment core stratigraphy of SCM41E

Depth (cm)	Sediment colour
0-119	Dark brown/black

A piston core, 0.78 m in length (SCM41F), was collected from Tatton Mere on 16-Feb-10 in 5.3 m water depth, in a shallow water zone at the northern end of the lake, approximately 100 m offshore.

There were several notable changes in the core (Figure 12). The upper 0-18 cm was dark brown/black in colour with few visible remains, except for a large piece of wood found in the 17-18 cm sample. The colour changed gradually and from 18-45 cm the sediment was mid-brown with woody remains and was more consolidated than the upper part of the core. The section from 45 cm to the core base was mid-brown but had higher peat content with larger woody remains and was more fibrous in nature, especially below 60 cm. Large *Potamogeton* seeds were observed in the intervals 60-61cm, 70-71 cm and 75-78 cm, and large woody remains were seen in the 72-78 cm section at the bottom of the core.

Figure 12 Sediment core stratigraphy of SCM41F

Depth (cm)	Sediment colour
0-18	Dark brown/black
18-45	Mid-brown with woody remains
45-78	Mid-brown but higher peat content than upper sections with large woody remains

The visual homogeneity of the open water core (SCM41E) was reflected by the stratigraphic data which exhibited little variation downcore (Figure 13). The DW% values were low throughout at ~10-15% and the %LOI values were relatively high at ~30% below 50 cm, slightly lower at ~20-25% from 10-50 cm and then increased again slightly towards the surface to 27%. However, all changes were gradual and there were no marked horizons in the core. The carbonate content was low throughout with values fluctuating between 3 and 6%.

The stratigraphy of the marginal core (SCM41F) was rather different (Figure 14). Whilst the DW% and carbonate content values were similar in range to those in the open water core, the organic matter profile was markedly different. Values of LOI% below 45 cm in the marginal core were in excess of 50% and increased downcore to 94% at the base. This coincides with the peaty section of the record and is, therefore, almost entirely organic

matter. The LOI% values from 18-45 cm were considerably lower, fluctuating between 30 and 50% and the uppermost 18 cm had lower values still, being stable at ~20%. The main changes in the organic matter content mirrored the visual changes observed during extrusion of the core.

Figure 13 Percentage dry weight (DW), organic matter (LOI) and carbonate (CO_3) profiles of SCM41E

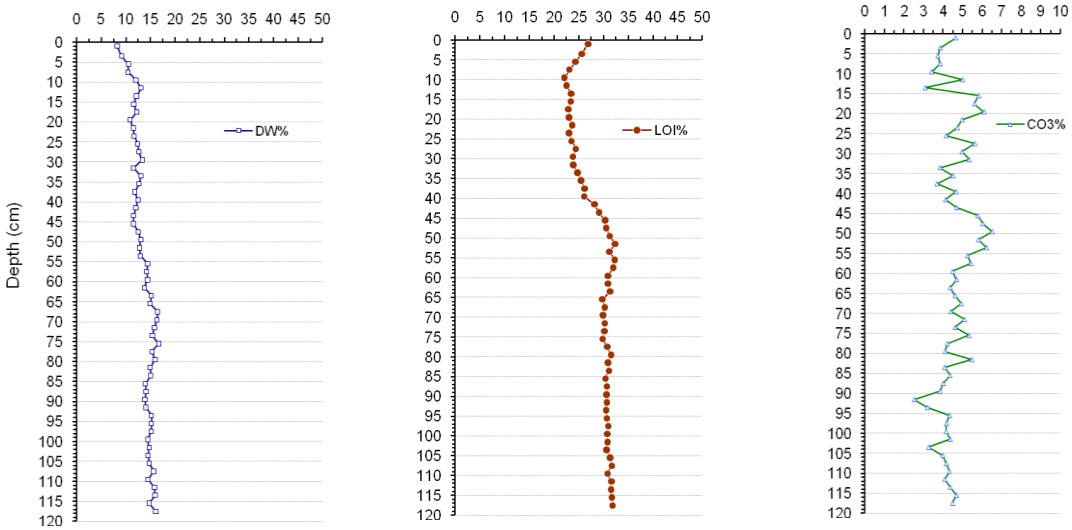
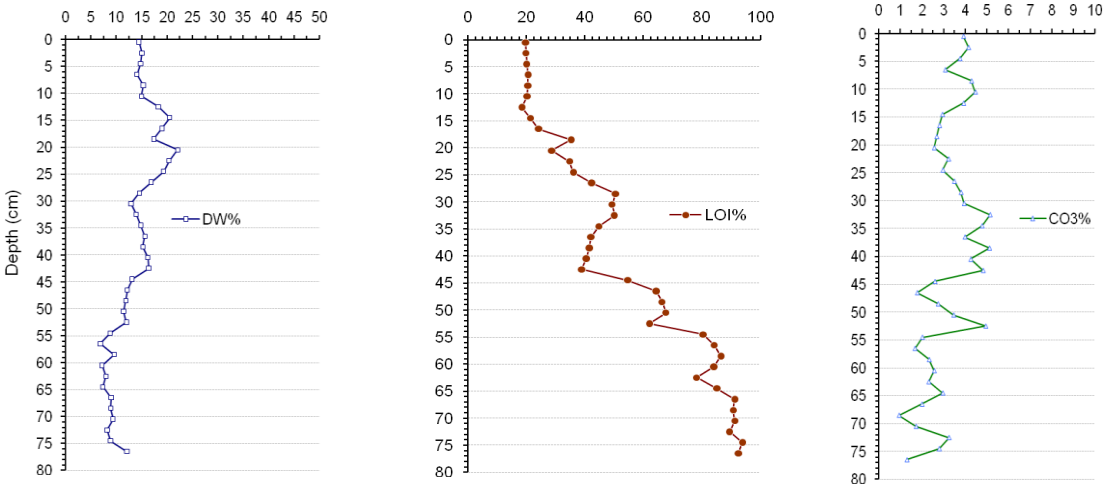


Figure 14 Percentage dry weight (DW), organic matter (LOI) and carbonate (CO_3) profiles of SCM41F



4.2 Dating

4.2.1 Open water core (SCM41E)

The SCP concentrations for SCM41E, the open water core from Tatton Mere, are shown in Table 7 and Figure 15. A first presence of SCPs occurs at 79 - 80 cm and SCP concentrations increase steadily to around 45 cm and then more rapidly to 20 cm when they increase dramatically to a peak of over 51000 gDM^{-1} at 14 – 15cm. Concentrations then decrease rapidly again to the sediment surface.

In this core, the SCP concentration peak is well defined and although the sample resolution means it could lie between 11-18 cm it is most likely to fall in the middle of this range. The depth of 14 – 15 cm may therefore be ascribed the date of 1978 ± 4. The mean sediment accumulation rate for the last 32 years would therefore be 0.453 cm yr^{-1} (or a range of 0.344 – 0.562 cm yr^{-1} considering the range of possible peak depths). As with the Melchett Mere core, the rapid increase feature (~1950) is not obvious in SCM41E, but extrapolation of the mean sedimentation rate for 1978 – 2010 would put 1850 at ~70 – 75 cm. This is not so far out from the observed start of the SCP record and therefore it is likely that the SCP record is intact. This being the case we can use the cumulative SCP inventory approach (Rose & Appleby, 2005) to date this core. This provides a date for each 10-percentile of the SCP record providing 11 dates rather than three using the alternative approach. The chronology for SCM41E based on this approach is given in Table 8.

Figure 15 SCP profile for SCM41E

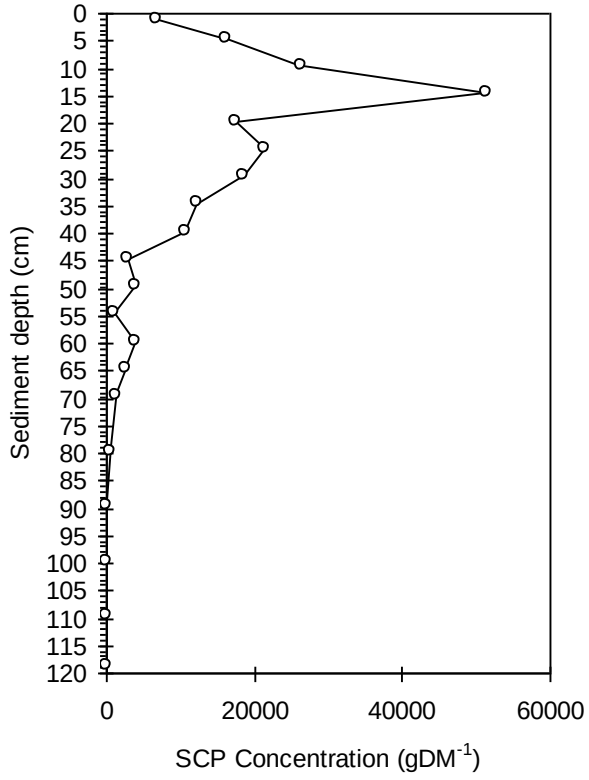


Table 7 SCP concentrations for SCM41E

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
1	6781	1661
4.5	16077	2626
9.5	26445	3863
14.5	51439	5900
19.5	17569	2460
24.5	21319	3389
29.5	18604	2919
34.5	12219	2151
39.5	10651	2334
44.5	2787	1032
49.5	3901	1445
54.5	958	664
59.5	3808	1866
64.5	2619	1048
69.5	1177	1153
79.5	500	490
89.5	0	0
99.5	0	0
109.5	0	0
118.5	0	0

Table 8 Chronology for the open water core SCM41E from Tatton Mere

Sediment depth (cm)	Age (Years)	Date
0	0	2010
14.5	32 ± 4	1978 ± 4
17.5	36 ± 5	1974 ± 5
20	45 ± 5	1965 ± 5
23	48 ± 6	1962± 6
26	50 ± 10	1960 ± 10
30	55 ± 15	1955 ± 15
34	70 ± 15	1940 ± 15
38	90 ± 20	1920 ± 20
44	100 ± 20	1910 ± 20
58	120 ± 25	1890 ± 25
80	160 ± 25	1850 ± 25

4.2.2 Marginal core (SCM41F)

The SCP concentrations for SCM41F, the marginal core from Tatton Mere, are shown in Table 9 and Figure 16. A first presence of SCPs occurs at 44 - 45 cm and concentrations remain low to around 20 cm when they increase dramatically to a peak of over 16000 gDM^{-1} at 9 – 10 cm. Concentrations decline erratically to the sediment surface. Assuming the SCP concentration peak at 9 – 10cm is 1978 ± 4, then this indicates a mean sediment accumulation rate of 0.297 cm yr^{-1} for this period. Extrapolating this rate would place 1950 at ~18 cm and 1850 at ~47 – 48 cm both of which fit very well with the observed SCP concentration record. This would imply a consistent sediment accumulation at this coring location for the last 160 years. The only caveat here is that the lower half of the SCP concentration profile is a little unusual in that low concentrations (0 gDM^{-1} at 24 – 25cm) are followed by a very sharp increase. Because of this, the cumulative SCP inventory approach has not been applied to this core. However, assuming that our interpretation of the profile is correct, the dates for this core are shown in Table 10.

Figure 16 SCP profile for SCM41F

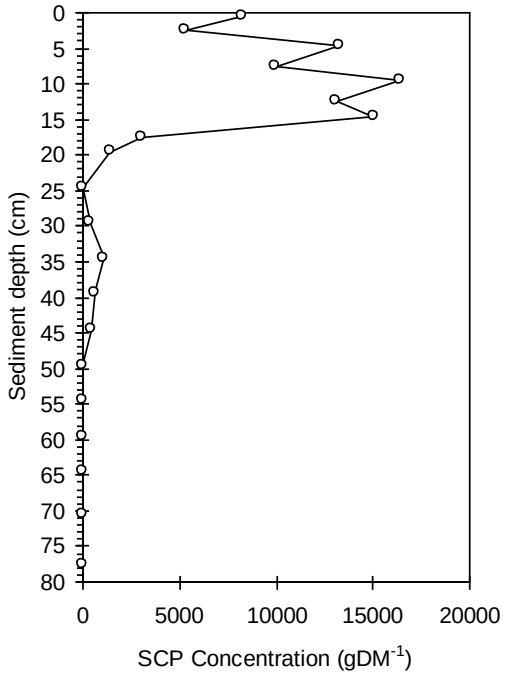


Table 9 SCP concentrations for SCM41F

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	8261	1810
2.5	5334	1397
4.5	13264	2771
7.5	9915	2072
9.5	16441	1968
12.5	13126	1962
14.5	15053	2649
17.5	3056	998
19.5	1398	518
24.5	0	0
29.5	357	350
34.5	1054	1033
39.5	668	655
44.5	460	451
49.5	0	0
54.5	0	0
59.5	0	0
64.5	0	0
70.5	0	0
77.5	0	0

Table 10 Chronology for the marginal core SCM41F from Tatton Mere

Sediment depth (cm)	Age (Years)	Date
0	0	2010
5	17 ± 4	1993 ± 4
10	34 ± 4	1976 ± 4
15	51 ± 10	1959 ± 10
20	68 ± 15	1942± 15
25	85 ± 20	1925 ± 20
30	102 ± 20	1908 ± 20
35	119 ± 25	1891 ± 25
40	136 ± 25	1874 ± 25
45	153 ± 25	1857 ± 25

4.3 Diatom analysis

Eleven samples were analysed for diatoms in the SCM41E core (Table 11). Preservation of the diatom valves was reasonable throughout the core and a total of 80 diatom taxa were observed with between ~20-36 taxa recorded per sample. The results for the major diatom taxa are shown in Figure 17.

Although *Stephanodiscus parvus* was common throughout, there were marked changes within the other taxa during the period represented by the core and cluster analysis identified three zones: Zone 1, from the core base to ~100 cm (pre-1850), Zone 2 from ~100 – 45 cm (pre 1850 - ~1910) and Zone 3 from ~45 cm to the surface (~1910 to present). The surface sample was also identified as being significantly different from the adjacent samples, but is included in Zone 3 for ease of interpretation.

Zone 1 (pre-1850) comprised mainly of two planktonic species: *Stephanodiscus parvus* and *S. neoastraea.*

Zone 2 was also dominated by plankton, but *Stephanodiscus neoastraea* declined significantly in Zone 2 and *Stephanodiscus parvus* increased to over 70% of the assemblage with *Stephanodiscus hantzschii* also common; a flora typical of enriched waters.

Zone 3 was also dominated by plankton with *Stephanodiscus parvus* still at ~ 50%, but with *Cyclostephanos dubius* becoming common at around 1910-1950. From ~1950 *Stephanodiscus hantzschii*, *Aulacoseira ambigua, A granulata* and *Asterionella formosa*, became more abundant. The surface sample showed a marked decline in *S. parvus* and *S. hantzschii* and an increase in *Aulacoseira ambigua*; a species usually associated with only moderate nutrient enrichment.

The diatom results appear to indicate that Tatton Mere has been a relatively nutrient-rich, plankton dominated site since well before 1850. The species shifts observed through the core are recorded by the PCA axis 1 scores which are being driven primarily by the abundance of *S. parvus* and thus only the uppermost and base sample have high PCA axis 1 scores due to a slight drop in the abundance of this taxon. The SCD scores are relatively high (>0.5) indicating the difference between all samples from the basal sample. A maximum of ~1.0 SCD unit was calculated for the top sample reflecting the presence of *Aulacoseira* spp. at the top of the core which were absent from the base of the core and the negligible amounts of *S. neoastraea* in the surface sample compared to the high relative abundance of this species at the core bottom.

The DI-TP reconstruction suggests that TP concentrations have been relatively high at ~150-200 µg L^{-1} in Tatton Mere since well before ~1850 (i.e. the entire period covered by the sediment core). There does, however, appear to be a gradual increase in TP from the pre-1850 samples to a peak in ~1920, after which values stabilise at ~180 µg L^{-1} until the 1990s. The surface sample suggests a recent drop in TP in Tatton Mere with the WA-PLS component 1 model inferring a current value of 124 µg L^{-1}. Measured mean annual TP for the site ranged from 112 – 214 µg l^{-1} (2005 – 2009, Goldsmith 2010) and therefore the DI-TP (1) model for the surface sediment does appear to approximate the current conditions at Tatton Mere.

In summary, the diatom assemblages of Tatton Mere have been dominated by a planktonic flora since at least 1850. There appears to have been a slight increase in the diatom-inferred TP at the site reaching a maximum of ~200 µg L^{-1} in the early 1900s. More recently the DI-TP seems to have stabilised at ~180 µg L^{-1} until the last ten years when inferred concentrations have declined.

Table 11 Results of the diatom analysis on SCM41E

Depth (cm)	No. of taxa	N2	DI-TP (1) µg L^{-1}	DI-TP (2) µg L^{-1}	SCD	PCA axis 1 scores
1	28	5.43	124	94	0.99	1.31
10	28	2.77	183	165	0.85	0.23
20	36	2.78	172	154	0.76	0.07
30	32	2.85	179	161	0.79	0.14
40	36	4.04	209	192	0.82	0.73
50	23	1.59	187	163	0.71	-0.77
60	21	1.34	181	157	0.70	-1.07
70	30	2.00	182	159	0.62	-0.41
80	24	1.33	187	163	0.76	-1.09
90	30	1.93	175	149	0.45	-0.40
110	31	3.51	157	126		1.26

4.4 Macrofossil analysis

4.4.1 Plant macrofossils

Ten samples were analysed for plant macrofossil remains in the SCM14F core (Table 12). A total of 28 taxa were observed in the core and a summary diagram for the major taxa is presented in Figure 18. The cluster analysis identified three zones in the Tatton Mere macrofossil record.

Zone 1 (70-55 cm, ~pre-1800) contained *Nymphaea alba* seeds and seed fragments, and *Nymphaeaceae trichosclereids*. *Menyanthes trifoliata* seeds, *Carex* seeds and *Ranunculus* sect. *Batrachium* seed fragments were also present within this zone. Two *Chara* oospore morphotypes ('oval' and 'hairy oval') were represented with *Chara* (oval) oospores reaching relatively high numbers in the bottom sample (285 oospores per 100 cm^3). Two *Potamogeton* seed types were also identified in this zone (*P.* cf. *natans* and *P. obtusifolius*) with some fine-leaved *Potamogeton* leaf fragments also present.

In Zone 2 (55-15 cm, representing ~1800–1960) aquatic species diversity reached a maximum with 16 taxa observed in the 50 cm sample (Table 12). *Gleotrichia* spp. *Menyanthes trifoliata* seeds, *Carex* seeds, *Ranunculus* sect. *Batrachium* seed fragments, *Nymphaea alba* seeds and seed fragments, and *Nymphaeaceae trichosclereids* were all present but decreased towards the top of Zone 2. *Myriophyllum* seeds and *Nitella* oospores ('hairy' type) were also present in the lowermost samples of Zone 2 but absent from the rest of the record. Two other *Nitella* oospore morphotypes occurred in Zone 2, but *Chara*

oospores were relatively scarce throughout the zone. *Potamogeton obtusifolius* leaf tips, *Potamogeton pusillis* seeds, *Potamogeton* fine-leaved fragments and unidentified decayed *Potamogeton* seeds were also present within this zone.

Zone 3 (15-0 cm, ~1960-2010) comprised two samples and contained fewer macrofossil remains than Zone 2. *Chara* oospores ('oval' type) were present in both samples but increased in the uppermost sample to 172 oospores per 100 cm^3. *Chara* oospores ('long' type) occurred in the uppermost sample only. In contrast no *Nitella* oospores were found within the Zone 3 samples. *Potamogeton* fine-leaved fragments, *Potamogeton berchtoldtii/pusillis* leaf tips, *Callitriche* seeds and *Zannichellia palustris* seeds were also present throughout Zone 3.

Table 12 Results of the plant macrofossil analysis on SCM41F

Depth (cm)	No. of taxa	N2
2	9	1.84
10	7	4.15
20	12	3.25
25	9	4.81
30	6	2.98
40	10	2.70
45	12	4.11
50	16	5.12
60	8	3.35
70	11	2.28

4.4.2 Zooplankton ephippia

The cluster analysis identified two zones in the Tatton Mere ephippia record (Figure 19).

In Zone 1 (75-35 cm, ~pre-1800-1890) zooplankton ephippial remains were scarce at the base with relatively low numbers of *Ceriodaphnia* spp. occurring at 70 cm. Towards the top of Zone 1 *Ceriodaphnia* and *Simocephalus* spp. numbers both increased.

In Zone 2 (35-0 cm, ~1890-2010) ephippial species diversity increased. Abundances of *Daphnia hyalina* agg*., Daphnia pulex* and the large-bodied pelagic species *Daphnia magna* increased dramatically in the upper core samples (post-1960), with *Ceriodaphnia* and *Simocephalus* spp. occurring in low numbers in the uppermost sample.

4.5 Cladocera analysis

Twelve samples were analysed for chitinous cladoceran remains in the SCM41E core (Table 13). A total of 25 taxa were observed in the core and a summary diagram for the major taxa is presented in Figure 20. Three zones were identified by cluster analysis.

Zone 1 (100-45 cm, pre-1850 to ~1910) was dominated by the open-water species *Bosmina coregoni* (52-70% relative abundance) with *Bosmina longirostris*, *Chydorus sphaericus* and *Alona quadrangularis* frequently present. The SCD scores remained low and the PCA axis 1 scores were relatively constant reflecting the stability of the assemblages in this zone.

In Zone 2 (45-7.5 cm, ~1910-1995) there was an increase in species diversity and the most notable change was the exchange in dominance of *B. coregoni* and *B. longirostris*, with the latter becoming most abundant. The increased abundance and diversity of plant-associated species, such as *Acroperos harpae, Alona affinis* and *Eurycercus lamellatus* coincided with

an increase in the plant-related cladoceran *Simocephalus* spp. in the ephippia data. The SCD scores rose sharply in this zone to ~1.0 reflecting the deviation of the assemblage from that seen at the base of the core. Similarly the PCA axis 1 scores changed abruptly at the Zone 1//2 boundary indicating the large compositional shift.

Zone 3 (7.5-0 cm, ~1995-2010) was similar in species composition to that of Zone 2, with slightly higher numbers of *Daphnia hyalina/longispina* agg. The latter was observed to a greater extent in the ephippial data. The SCD scores remained high and PCA axis 1 scores were relatively stable in this zone as *B. longirostris* continued to dominate the assemblages.

Table 13 Results of the Cladocera analysis on SCM41E

Depth (cm)	No. of taxa	N2	SCD	PCA axis 1 scores
0	17	3.48	0.95	-0.62
5	19	3.34	1.2	-0.91
10	19	3.14	0.86	-0.69
15	15	2.84	0.93	-0.78
20	15	2.92	0.73	-0.34
30	12	2.48	0.98	-0.94
40	14	1.97	1.23	-1.27
50	13	3.23	0.17	0.85
60	12	2.30	0.29	0.86
70	15	2.12	0.09	1.36
80	16	2.23	0.07	1.30
100	16	2.57		1.2

4.6 Pigment analysis

Thirteen samples were analysed for sedimentary pigments in the SCM14E core. A total of 12 chlorophylls and carotenoids were observed in the core and a summary diagram for the major taxa is presented in Figure 21. Concentrations of pigments were moderate-high and labile pigments were present throughout the core, indicating good preservation. The cluster analysis identified four zones in the Tatton Mere pigment record.

Zone 1 (118-95 cm, ~pre-1800) had low concentrations of all pigments, indicating the lowest levels of aquatic primary production throughout the core. All pigments are represented in this zone, indicating the presence of siliceous algae, cryptophytes, chlorophytes and cyanobacteria.

In Zone 2 (95-35 cm, representing ~1800– 1940) concentrations of pigments from siliceous algae, cryptophytes and chlorophytes steadily increased. Cyanobacteral pigments, zeaxanthin and canthaxantin, showed a similar increase whereas echinenone maintained stable concentrations, implying shifts in the structure of the cyanobacterial community (although it is not possible to denote the taxonomic shifts using pigments alone). Towards the top of the zone there was an abrupt increase and then a decline in lutein and pheophytin *b* (pigments from chlorophytes and higher plants). These shifts may be related to changes in aquatic plant abundance, and shortly pre-date the decline in aquatic plant diversity recorded in the macrofossils (~1960).

Zone 3 (35-15 cm, ~1940-1980) registers an increase in siliceous algae and cryptophytes, and some cyanobacteria (canthaxanthin). However, concentrations of chlorophyte and aquatic plant pigments either remain stable (lutein), increase (Chl b) or decline (pheophytin *b*). This pattern may be recording a decline in aquatic macrophytes (as pheophytin b, which is produced in situ as plants senesce), whilst planktonic taxa concurrently increase. Echinenone disappears in this zone, suggesting a loss of some components of the

cyanobacterial flora, but maintenance of zeaxanthin and canthaxanthin shows that other cyanobacteria persist in the lake.

In Zone 4 (15-0 cm, ~1980-2010) there was an abrupt increase and then a decline in most pigments, indicating an increase to maximum levels of aquatic production followed by a reduction in the most recent period. The exception to this pattern is fucoxanthin, which increases in the upper sediments, but these elevated concentrations may be driven by incomplete degradation of this labile pigment in the uppermost sediments.

4.7 Application of macrophyte-nutrient models

The most striking feature of the macrofossil-based reconstruction for Tatton Mere is the marked rise in TP from 26 cm (~1960) to 10 cm (~1980) when inferred concentrations more than doubled (Figure 22). This is all the more marked since, until that time, the macrofossils suggest declining fertility. Over the last 20 years or so inferred concentrations have declined but remain high relative to the historic baseline. In real terms, based on the locally calibrated model, this suggests a rise in TP concentrations from 64 µg L^{-1} (90 % confidence limits 27 – 152) at the core base to 133 (55 - 319) µg L^{-1} at the top.

The macrofossil reconstruction for the core surface exhibits a good fit with the reconstruction based on the contemporary (2001) vegetation for this site described in Lockton *et al.* (2001). As a reference point for the base of the core we used historical botanical records from the mid-1800s for a number of better recorded meres in the vicinity (Rostherne, Mere Mere, Tabley, Budworth and Pickmere), there being a virtual absence of historical records of aquatic plants definitively assignable to Tatton Mere until the late 1960s. These combined approaches suggest a rise in macrophyte-inferred TP from 68 – 76 µg L^{-1} over the last ~150 years, equivalent to real term change rise in TP from 103 (43 - 246) to 147 (61-353) µg L^{-1}. The macrofossil reconstruction for the base of the core (70 cm) also shows a close match with the reconstruction based on the mid-1800s historical record archive for adjacent water bodies, and there is a similarly good tie in between current vegetation and macrofossils in the top of the core for the prediction of contemporary fertility. By way of additional support there is also a good match between reconstructed TP at the core base and that in the immediately adjacent Melchett Mere.

Although Tatton Mere appears to be at least partly fed by surface runoff, and therefore potentially more vulnerable to the influence of point source inputs upstream than Melchett Mere, both macrofossil and historical record approaches imply that enrichment has been less acute at Tatton than at Melchett Mere (although see Discussion below regarding difficulties in defining baseline conditions for Melchett Mere owing to its recent formation).

4.8 Discussion

The open water sediment core from Tatton Mere extends back to ~1800 AD based on extrapolation of the SCD derived accumulation rates, whilst the marginal core extends back a little further to ~1750 AD. The palaeoecological data indicate that Tatton Mere has been a nutrient-rich lake for the whole of the period represented by the cores, i.e for approximately the last 200 years. The diatom community in the basal sample contains high amounts of *Stephanodiscus neoastraea*, a species commonly found in lakes of intermediate nutrient concentrations, but also contains ~40% *Stephanodiscus parvus*, which is an indicator of nutrient-rich conditions. Hence DI-TP concentrations even at the bottom of the core are high with values of ~120-150 µg L^{-1}. While the lowest concentrations of all pigments were found at the bottom of the core, all pigments were represented, indicating the presence of siliceous algae, cryptophytes, chlorophytes and cyanobacteria at this time. The zooplankton data indicate that the community was relatively diverse at the base of the core with *Bosmina coregoni* being the dominant species in the chitinous remains. This is a pelagic species that feeds on planktonic algae and, therefore, indicates high planktonic production. This is

consistent with the diatom data which indicates dominance of planktonic taxa (~80% of the total assemblage). However, it should be noted that the chitinous Cladocera analysis was carried out on the open water core collected in a water depth of ~11 m and thus littoral taxa may be under-represented. The aquatic macrophyte flora was structurally diverse in the early period of the core comprising several taxa associated with lakes of moderate productivity such as *Menyanthes trifoliata, Myriophyllum* spp., a number of *Chara* taxa, *Ranunculus* sect. *Batrachium, Potamogeton* cf. *natans* and *Potamogeton obtusifolius*. Nevertheless, the site appears to have been eutrophic for a long period and it would seem that a longer core is needed to extend the record back to the pre-enrichment period.

The first major change occurs in the palaeo-record in the mid-1800s with the expansion of the eutrophic diatom species *Stephanodiscus parvus* to values of ~80% which is maintained for approximately 100 years. This is a spring blooming taxon and therefore it is likely that there was spring diatom dominance from the mid-1800s to the early 1900s. Consequently DI-TP values increase to ~160-180 µg L^{-1} and remain high. Concentrations of pigments from all algal groups also steadily increase from around this time. The chitinous Cladocera assemblages continue to be dominated by *Bosmina coregoni* (~60%) throughout the 1800s reflecting high abundance of planktonic algae as a food source. The timing of these changes is coincident with the first observed shifts in the plant macrofossil record, notably a decrease in the abundance of *Chara* oospores and an increase in Nymphaeaceae trichosclereids from the mid-1800s. The latter are vegetative remains whilst the seeds are produced sexually so it is interesting to observe that *Nymphaea alba* seeds decline after ~1850 whilst the trichosclereids increase. This could be due to enrichment of the site which can cause the plants to stop producing seeds and to produce only vegetative remains. Further changes in the plant macrofossil record occurred at ~1850 with the disappearance of *Menyanthes trifoliata, Myriophyllum* spp. *Potamogeton* cf. *natans* and *Potamogeton obtusifolius* seeds. In contrast *Nitella* spp *Potamogeton pusillis* seeds, *Potamogeton* fine-leaved fragments and unidentified decayed *Potamogeton* seeds appeared for the first time and overall plant diversity slightly increased. These changes signal a shift towards a more eutrophic flora.

Another point of change in the record was at ~1910. Here the relative abundance of *Stephanodiscus parvus* declined and the diatom plankton became more diverse comprising taxa that occupy not only the spring period but several that typically occur in the summer and autumn months (e.g. *Aulacoseira granulata, Aulacoseira ambigua*). This suggests that the plankton were occupying a longer period of the year than in the past. Indeed Moss *et al*. (1992) recorded a dominance of diatoms in all periods of the year in Tatton Mere. Synchronous changes were seen in the Cladocera data where *Bosmina coregoni* dominance was replaced by *Bosmina longirostris* dominance. Both species are pelagic but the latter is a smaller species typically associated with eutrophic systems and the former occurs commonly in less productive waters. While this species shift may reflect enrichment of the lake the exact drivers of change are not known. There was also increased abundance and diversity of plant-associated Cladocera species, such as *Acroperos harpae, Alona affinis* and *Eurycercus lamellatus* which coincided with an increase in the plant-related *Simocephalus* spp. in the ephippia data. These shifts may be attributed to enhanced plant biomass arising from the increasing productivity of the lake through the early 1900s. During the early part of the twentieth century the plant macrofossil record continues to contain the same set of taxa as those observed in the late 1800s.

The next point of change in the plant macrofossil record occurs at ~1960 when there is a marked decline in *Nymphaea* remains and *Nitella* spp. and an increase in *Callitriche* spp. and *Zannichellia palustris*. The macrophyte-inferred TP reconstruction suggests enrichment with a marked increase in values at this time Similar changes to those seen in the plant community of Tatton Mere have been observed in several other English lakes including the Trinity Broads in Norfolk (Davidson *et al.,* 2008), Aqualate Mere, Hornsea Mere, Sunbiggin Tarn (Bennion *et al*., 2009) and Felbrigg Lake (Sayer *et al.,* 2010). A common feature is the decline in abundance of Charophytes and an increase in fine-leaved *Potamogeton* taxa, *Zannichellia palustris* and *Callitriche* as the sites become more eutrophic (e.g. Blindow,

1992). This is often associated with changes in the sediment structure to more fluid sediments. The floristic changes also have implications for the duration of the plant dominated period as *Chara* and *Nitella* can persist throughout the growing season while some of the fine-leaved pondweeds tend to experience early season growth and then crash in the summer (e.g. Sayer *et al*., 2010) thereby opening up an opportunity for the plankton to dominate and for conditions to become turbid. Indeed, changes in the pigment concentrations in the mid-1900s suggest a decline in aquatic macrophytes and a concurrent increase in planktonic taxa. Hence we see the replacement of a structurally diverse flora with a mix of seasonalities by a less diverse flora comprised of largely nutrient-rich taxa that dominate in the early season. The plant changes in the Tatton Mere core are coincident with large increases in *Daphnia* spp in the ephippia data, including *Daphnia pulex* and *Daphnia magna,* particularly from ~1960. These are large-bodied taxa and are effective grazers of phytoplankton and their increase is, therefore, indicative of an increase in pelagic productivity. The high numbers of *Daphnia magna* suggest that zooplantivory in the system is low as this species performs badly in the presence of fish.

The plant macrofossil data accord well with a recent plant survey conducted in 2008 in which *Callitriche* spp., *Chara* spp*., Lemna* spp*., Potamogeton berchtoldii* and other fine-leaved pondweeds (e.g. *P. crispus, P. pectinatus)* and *Zannichellia palustris* were recorded. Remains of all of these taxa were found in the recent sediments. *Elodea canadensis* and *Elodea nuttallii were* also observed in the 2008 survey but unfortunately *Elodea* does not leave identifiable remains in the sediment record. A recent site condition assessment (Goldsmith, 2010) concluded that overall the characteristic aquatic vegetation is species-rich and well distributed through the mere and fulfils the targets for eutrophic lakes. However, Tatton Mere cannot be regarded as in 'favourable' condition, due to the high frequency of the invasive, non-native species *E. nuttallii.*

In the uppermost samples of the core there is a possible hint of water quality improvement across several indicators. Firstly, diatom taxa typically associated with lower nutrient concentrations than *Stephanodiscus parvus* increase in abundance, most notably *Aulacoseira ambigua* and *Asterionella formosa*. Consequently the DI-TP values decline slightly at the core surface to ~100-120 µg L^{-1}. The mean TP for the period 2005-2009 is ~160 µg L^{-1} and therefore, with the exception of the surface sample, the diatom inferred values in Zone 3 agree well with the measured data. Nonetheless, Tatton Mere is currently hyper-eutrophic with mean annual TP concentrations well in excess of the target limit of 50 µg L^{-1} for this lake type. It is important to note that in spite of the positive species shifts there is no reversal of the diatom flora to that observed at the bottom of the core so the changes cannot be interpreted as a clear sign of ecological recovery. Secondly, there is an increase in *Chara* oospores in the surface sample with numbers being sufficiently high to suggest that this is a real increase and not an artefact of the surface sediment. The floristic change is reflected in the macrophyte-inferred TP concentrations which decline in the surface sample although not to baseline values. Finally, there is a decline in most pigments in the uppermost sample suggesting a decrease in aquatic production. In the absence of information on any potential reductions in nutrient sources it is not possible to determine whether these changes are a result of bottom up or top down factors. However, the recent increases in *Daphnia* spp. suggest that top-down control is likely to be operating at the site as the appearance of *Daphnia magna* is indicative of very low levels of zooplanktivory. Data on nutrient loads and fish populations would be required in order to fully explore the causes of these recent changes in the ecosystem. In support of our findings a report on the Tatton Meres by ECUS (2001a) stated that "recent data suggest that the water quality is improving". This appears to be based on a decline in measured nutrient concentrations in the lake. Continued monitoring of the site is recommended to see if these positive changes are sustained.

In summary the changes observed in the Tatton Mere sediment record are indicative of enrichment since around the early 1800s, which has continued through the twentieth century. Eutrophication has resulted in marked changes in the aquatic plant community from a structurally diverse flora with abundant Charophytes, nymphaeids and taxa with a mix of

seasonalities to a less diverse flora comprised of largely nutrient-rich taxa that dominate in the early part of the growing season. Nevertheless there are subtle signs of water quality improvement in the uppermost sample of the core with a decline in diatom taxa associated with highly nutrient-rich lakes, an increase in *Chara* remains and a decline in pigment concentrations. The lake was already moderately nutrient-rich at the base of the core and a longer core is required to extend the record back to a period when there was less anthropogenic activity in the lake catchment and thereby to define pre-enrichment reference conditions for the site. However, the study has provided information on the plant and animal communities that were present in the lake prior to the major eutrophication phase and this will be valuable for setting targets for future management of the site, particularly as historical plant surveys date back to only the mid-1960s and, therefore, do not describe the flora prior to enrichment.

Figure 17 Summary diatom diagram of Tatton Mere core, SCM41E

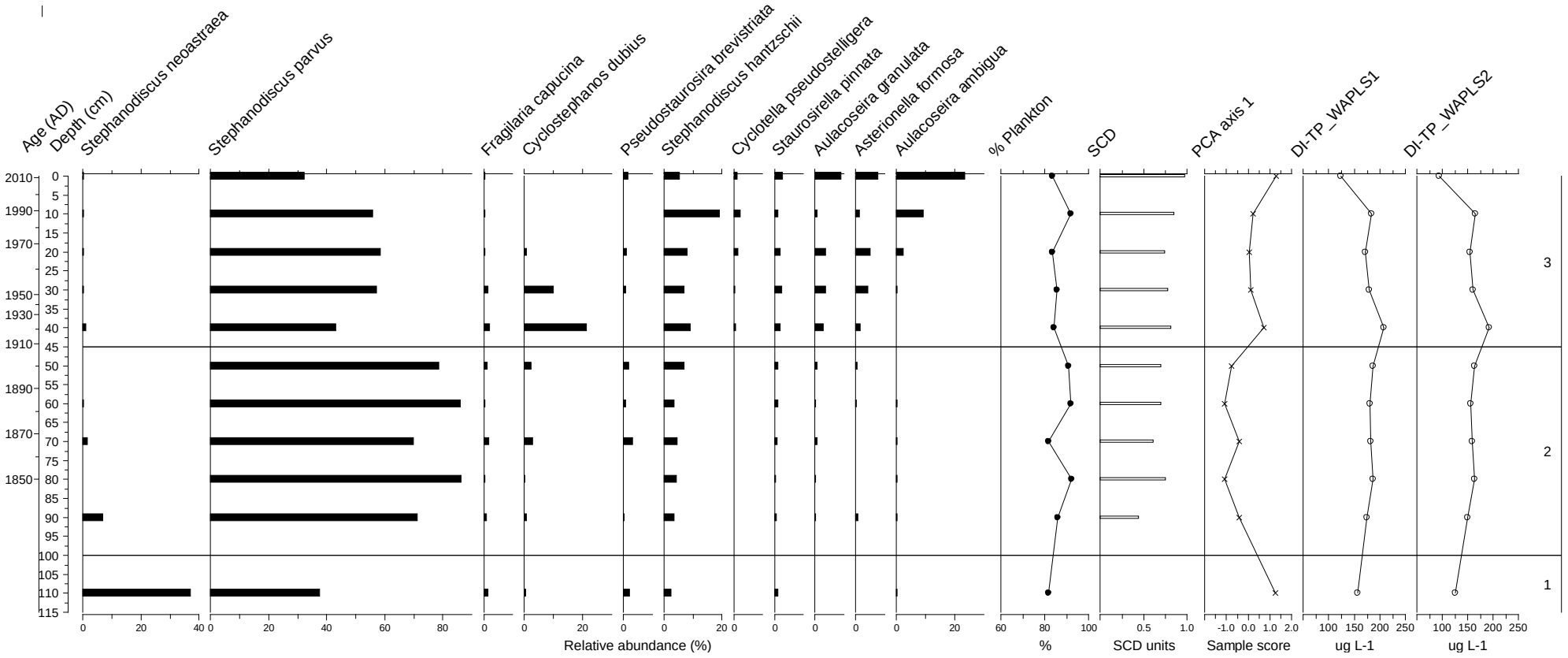


Figure 18 Summary plant macrofossil diagram of Tatton Mere core, SCM41F

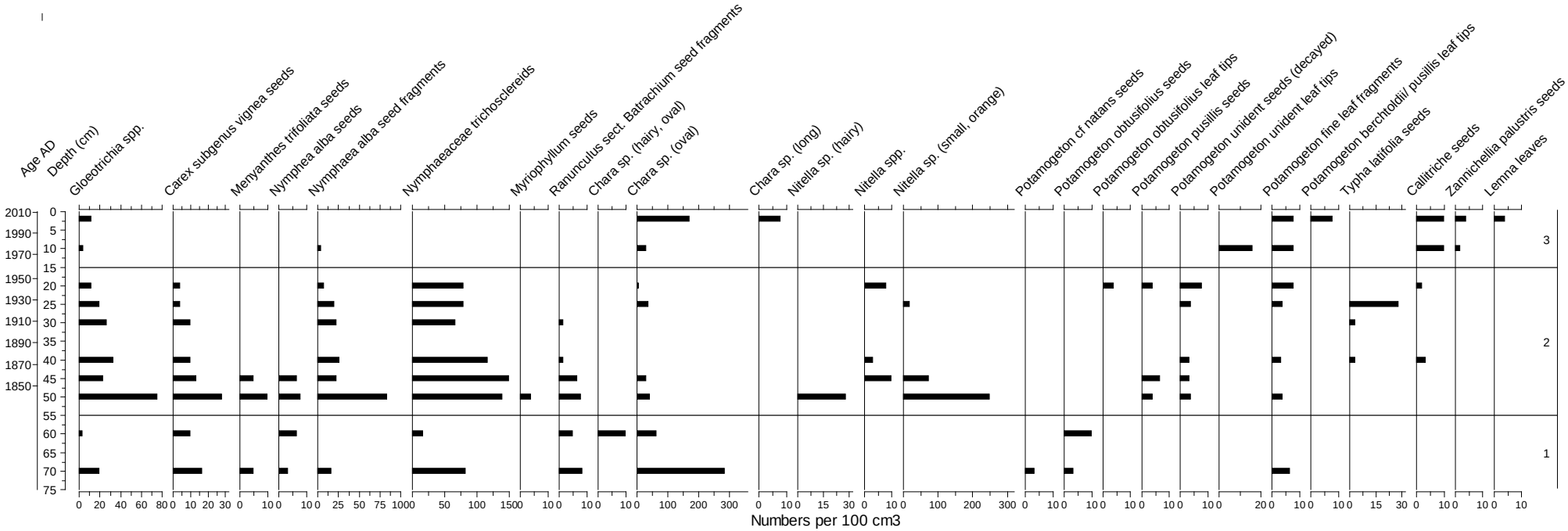


Figure 19 Summary zooplankton ephippia diagram of Tatton Mere core, SCM41F

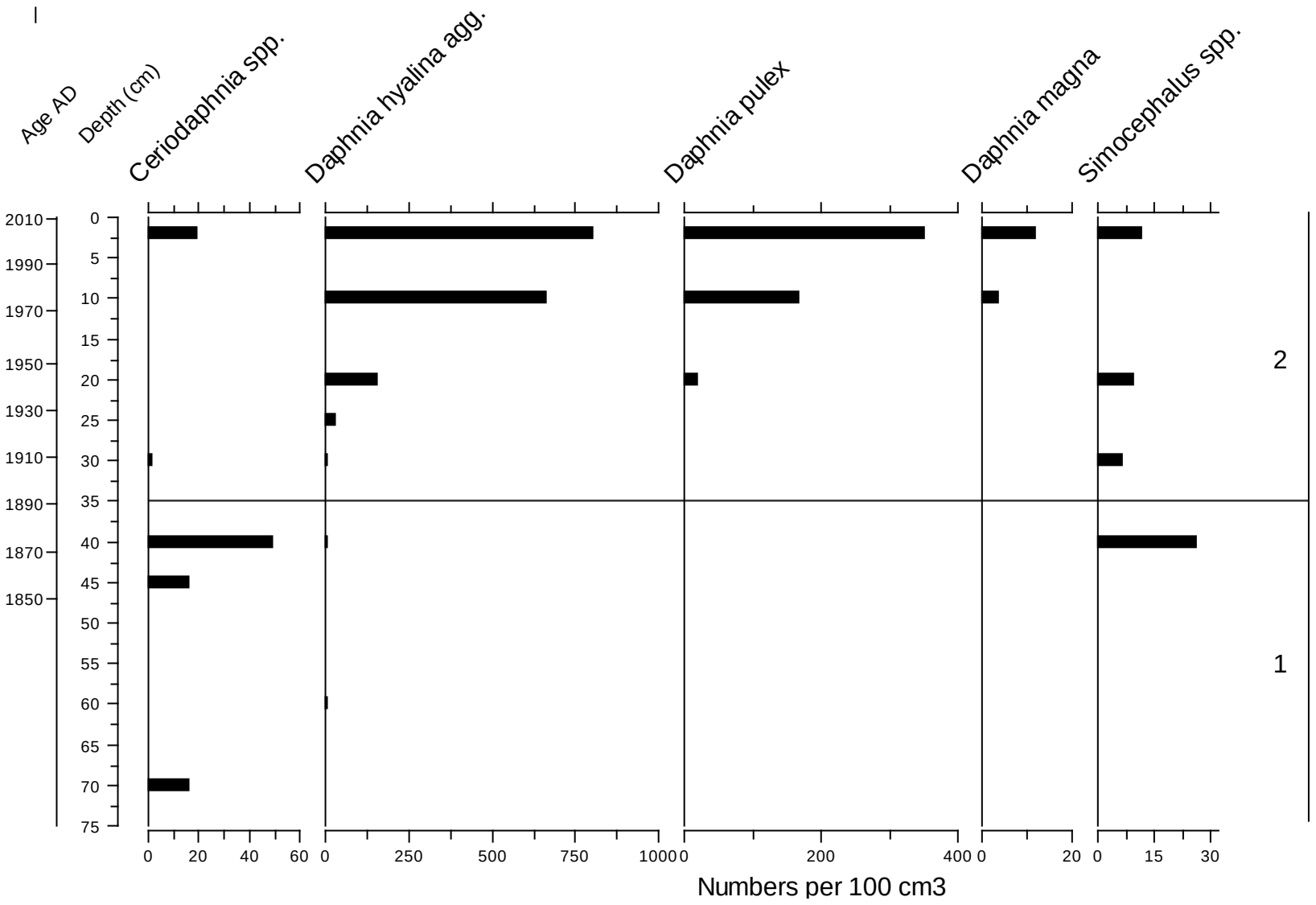


Figure 20 Summary Cladocera diagram of Tatton Mere core, SCM41E

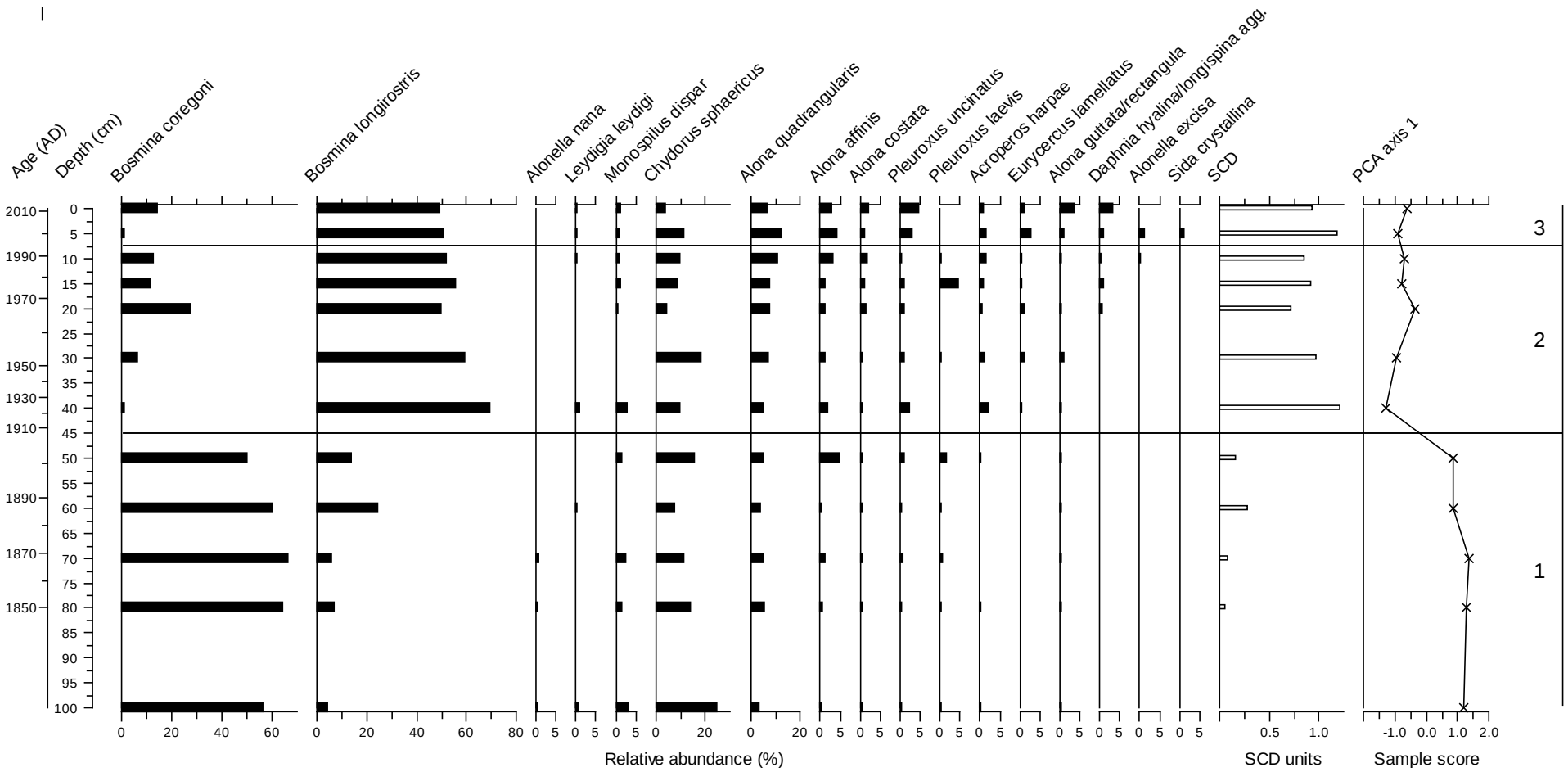


Figure 21 Summary pigment diagram of Tatton Mere core, SCM41E
(note variable scaling on the x axes (Concentrations in nanomoles per gram organic weight sediment; note variable scaling on the x axes)

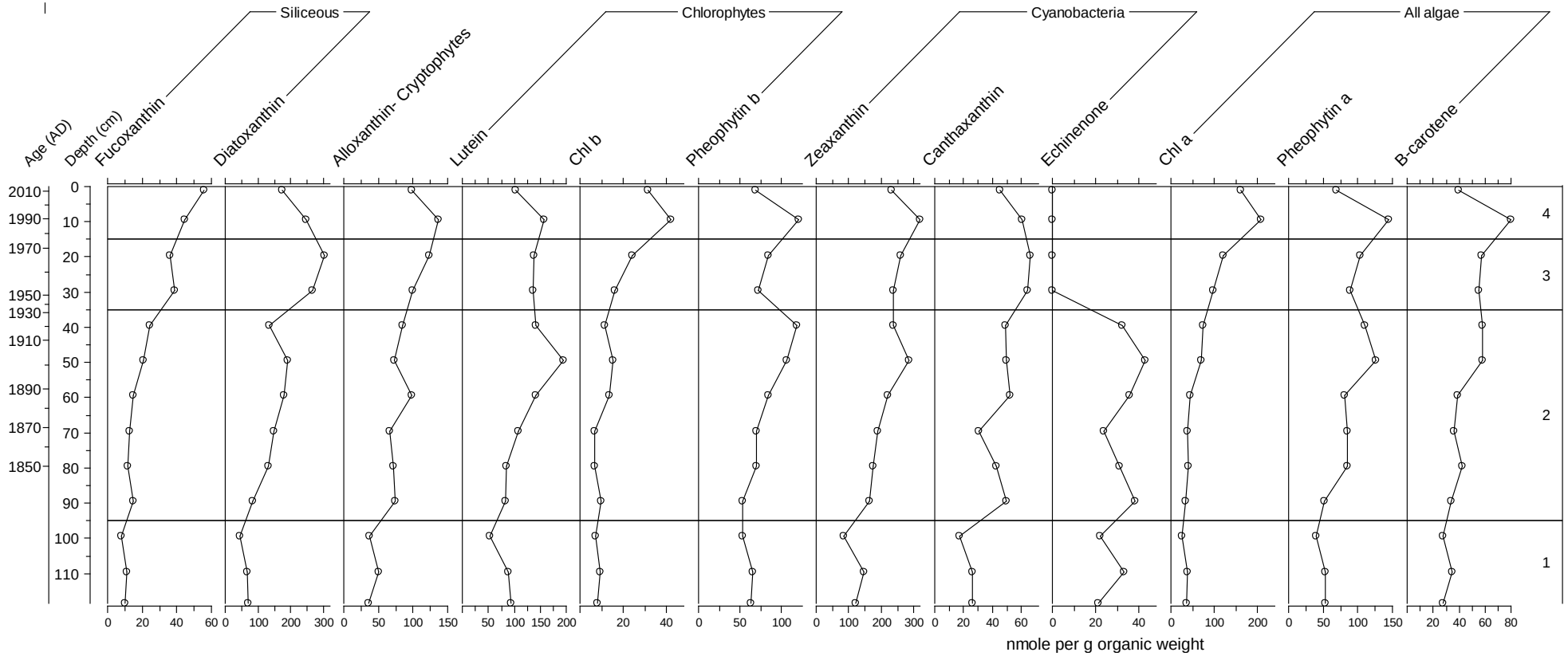
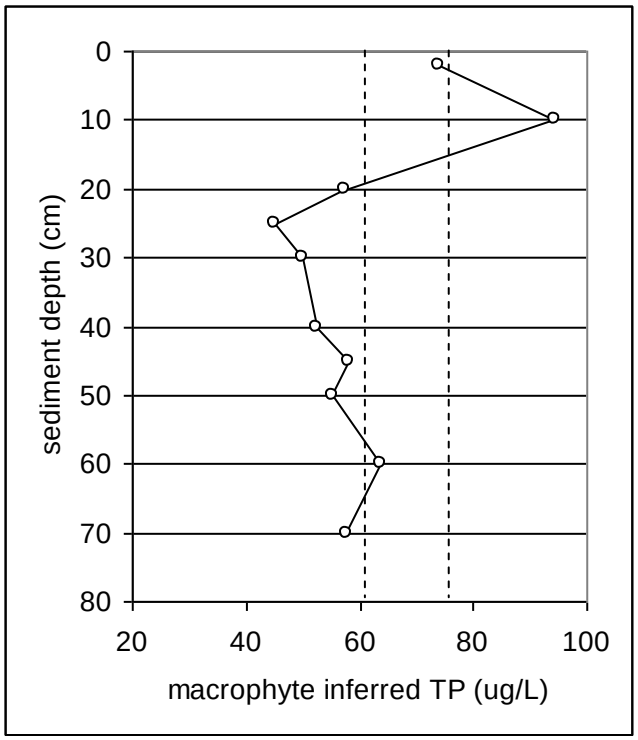


Figure 22 Macrophyte-inferred TP for Tatton Mere



Note: Points indicate macrofossil based reconstructions. Left hand dotted line indicates reconstructed mid-1800 TP using spatial analogue approach with historical record data from adjacent meres. Right hand line indicates reconstructed TP using contemporary vegetation.

5. COMBER MERE

5.1 Core description

A tapper core, 1.07 m in length (SCM14B), was collected from Comber Mere on 17-Feb-10 in 11.7 m water, in the deepest part of the basin.

The core had two horizons (Figure 23). The upper 50 cm was homogenous and dark brown in colour and the section below 50 cm was darker brown/black and was more consolidated with increasing clay content towards the core base.

Figure 23 Sediment core stratigraphy of SCM14B

Depth (cm)	Sediment colour
0-50	Dark brown
50-107	Dark brown/black

A piston core, 1.04 m in length (SCM14C), was collected from Comber Mere on 17-Feb-10 in 4.4 m water depth, in a shallow water zone at the eastern end of the lake, approximately 40 m offshore.

There were several notable changes in the core (Figure 24). The upper 0-26 cm was dark brown in colour with some mottling and visible mollusc remains. There was a gradual transition to mid-brown material from 26-68 cm brown, then light brown sediment from 68 cm to the core base.

Figure 21 Sediment core stratigraphy of SCM14C

Depth (cm)	Sediment colour
0-26	Dark brown with mollusc remains
26-68	Mid-brown
68-104	Light brown

The stratigraphic data for the open water core (SCM14B) indicates a gradual increase in organic matter up the core with LOI% values of ~12-14% below 50 cm, increasing to ~15-18% above 50 cm and reaching a maximum value of 20% at the sediment surface (Figure 25). The inverse pattern is seen in the DW% profile with the highest values of ~30% in the more consolidated, minerogenic lower layers, decreasing steadily to only ~10% at the top of the core. There are no abrupt changes in organic matter content in the record. Carbonate content also exhibits a gradual increase up the core from ~5% at the base to ~8% at 15 cm before rising rapidly in the upper 15 cm to ~20% at the surface.

In comparison with the open water core, the marginal core (SCM41C) exhibits major changes in organic matter content (Figure 26). Below ~70 cm the sediment is characterised by relatively low LOI% (< 30%) and high DW% (> 20%) values indicating fairly dense material with a large amount of mineral matter. In the section from ~30-70 cm the LOI% values are considerably higher, frequently > 45%, and DW% values are correspondingly low at ~12%, reflecting a marked increase in organic matter in this middle part of the record. The peak LOI% occurs at 45 cm, above which values begin to gradually decline again to ~25% at 25 cm. From 20 cm to 10 cm of the core the LOI% values decline rapidly to < 10% while DW% increase sharply to a maximum of ~60%. This signals a minerogenic layer in the profile. The LOI% values subsequently increase slightly to values of ~15% and DW% declines to ~20% towards the sediment surface. There is also a notable increase in

carbonate content from ~1-2% at 10 cm to ~5% in the uppermost 6 cm, although values are low throughout the core and are considerably lower than those seen in the upper section of the open water core. The increased carbonate content could reflect marl production in the sediment as abundant remains of mollusc shells were observed, especially in the marginal core.

Figure 25 Percentage dry weight (DW), organic matter (LOI) and carbonate (CO_3) profiles of SCM14B

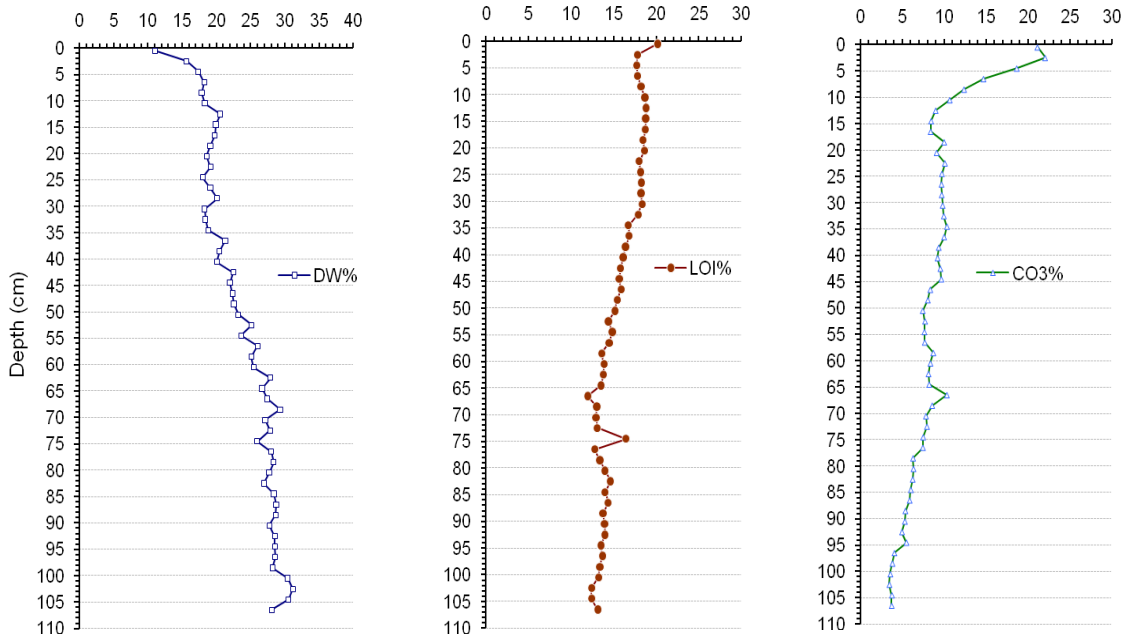
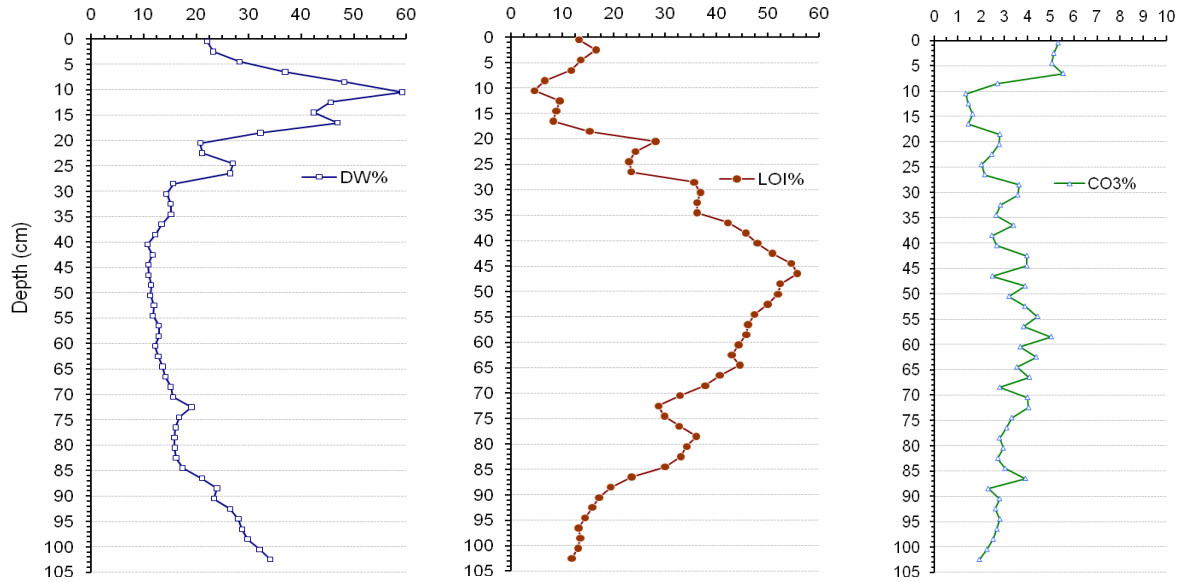


Figure 26 Percentage dry weight (DW), organic matter (LOI) and carbonate (CO_3) profiles of SCM14C



5.2 Dating

5.2.1 Open water core (SCM14B)

The SCP concentrations for SCM14B, the open water core from Comber Mere, are shown in Table 14 and Figure 27. A first presence of SCPs occurs at 44 - 45 cm but the profile has the appearance of being truncated. Concentrations increase steadily to around 10 cm and then rapidly to a peak of just over 5000 gDM^{-1} at 4–5 cm. SCP concentrations decline in the uppermost sample.

The SCP concentration peak at 4 – 5 cm is very close to the top of the profile suggesting either a major reduction in sediment accumulation rate in most recent times, or the loss of recent sediments. However as sample resolution is coarse the peak may also lie nearer 10 cm depth.

As with some of the other cores in this study described above the rapid increase in SCP concentration usually allocated to ~1950 is not easily identifiable but most likely occurs at around 20 cm. If this is the case and sediment accumulation rate has not varied greatly, then 1978 (± 4) would occur at ~10 cm. Similarly, using this same mean sediment accumulation rate, 1850 (± 25) would be expected to be at around 50 – 55 cm which is in reasonable agreement with the observed SCP profile. However, this chronology is rather speculative and should be treated with a degree of caution. A best available chronology for SCM14B may be summarised as follows:

- 1978 (± 4) at 8 – 10 cm
- 1950 (± 15) at ~ 20 cm
- 1850 (± 25) at 50 – 55 cm.

Figure 27 SCP profile for SCM14B

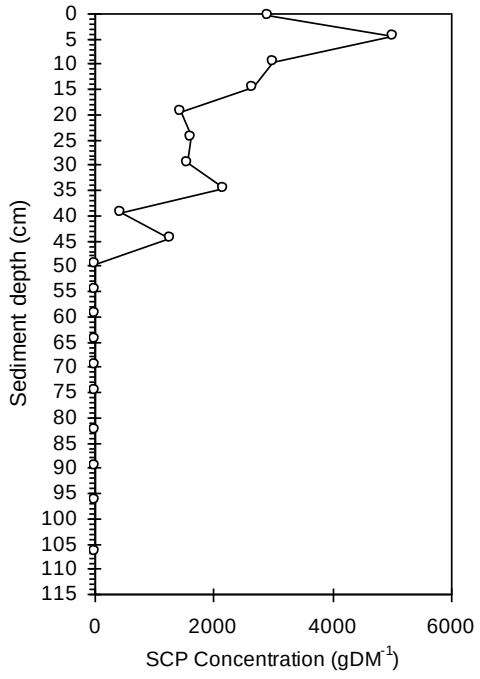


Table 14 SCP concentrations for SCM14B

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	2902	858
4.5	5027	1027
9.5	3012	890
14.5	2642	1158
19.5	1445	633
24.5	1619	561
29.5	1555	576
34.5	2173	1229
39.5	445	436
44.5	1278	560
49.5	0	0
54.5	0	0
59.5	0	0
64.5	0	0
69.5	0	0
74.5	0	0
82.5	0	0
89.5	0	0
96.5	0	0
106.5	0	0

5.2.2 Marginal core (SCM14C)

The SCP concentrations for SCM14C, the marginal core from Comber Mere, are shown in Table 15 and Figure 28. This core showed only a presence of SCPs in the uppermost two samples and concentrations were very low. The SCP record from SCM14C therefore provides no chronological information and the core cannot be dated by this means. The only conclusion that can be drawn is that sediments in the uppermost 5 cm of this core are younger than 1850.

Figure 28 SCP profile for SCM14C

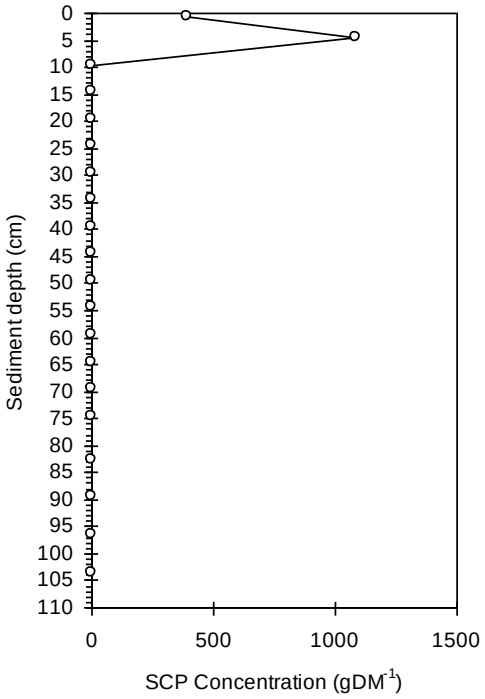


Table 15 SCP concentrations for SCM14C

Mean depth (cm)	SCP conc (gDM^{-1})	90% C.L. (gDM^{-1})
0.5	394	387
4.5	1088	1066
9.5	0	0
14.5	0	0
19.5	0	0
24.5	0	0
29.5	0	0
34.5	0	0
39.5	0	0
44.5	0	0
49.5	0	0
54.5	0	0
59.5	0	0
64.5	0	0
69.5	0	0
74.5	0	0
82.5	0	0
89.5	0	0
96.5	0	0
103.5	0	0

5.3 Diatom analysis

Ten samples were analysed for diatoms in the SCM14B core (Table 16). Diatom preservation was relatively good throughout the core and samples satisfactory for counting. A total of 76 diatom taxa were observed in the core with between ~30-42 taxa per sample, and the results for the major taxa are shown in Figure 29.

There were marked changes in the assemblages during the period represented by the core and cluster analysis identified two main zones: Zone 1 from the core base to ~35 cm (~pre-1910) and Zone 2 from ~35 to the core top (~1900 to present).

Zone 1 (~pre-1900) was comprised of approximately 50% planktonic taxa with *Cyclotella radiosa, Stephanodiscus parvus* and *S. neoastraea* most common. Non-planktonic taxa included small '*Fragilaria*' spp, *Planothidium lanceolatum, P. granum, Navicula subrotundata, Amphora pediculus* and *Achnanthes exigua*. The assemblages are typical of moderately enriched waters, but the presence of a high proportion of non-planktonic taxa suggest water clarity was relatively good; i.e. allowing light to reach the benthic habitats of the mere.

In Zone 2, *C. radiosa* and *S. neoastraea* decline significantly whilst several other planktonic taxa typical of more productive conditions increase in relative abundance towards the upper part of this zone, e.g. *Stephanodiscus parvus, Aulacoseira granulata, Cyclosephanos dubius* and *S. hantzschii.* Hence the planktonic component of the assemblage starts to increase from this time.

The diatom record indicates Comber Mere to have been relatively nutrient-rich, but stable prior to ~1900, with only subtle species shifts at this time. After ~1900 there appears to have been a phase of relatively rapid enrichment which has continued to the present day. The changes in the diatom assemblages through the core are recorded by the PCA axis 1 scores which show a marked decrease between 30 – 40 cm. The SCD scores are low (<0.5) in the core section below 15 cm and then gradually increase to values of 0.8, reflecting the progressive deviation of the diatom assemblages from those at the bottom of the core.

The DI-TP reconstruction suggests that TP concentrations were relatively high but stable prior to 35 cm at ~120 µg L^{-1}. Values then increase steadily reaching a maximum of ~180 µg Ll^{-1} in the surface sample. The measured mean TP between 2005 – 2009 was 187 µg L^{-1} and, therefore, corresponds very well with the modelled values.

The diatom record of Comber Mere indicates the site to have been eutrophic for at least the last ~200 years, but since ~1900 the trophic status has increased steadily, with a shift towards the dominance of planktonic diatoms and hence more turbid conditions.

Table 16 Results of the diatom analysis on SCM14B

Depth (cm)	No. of taxa	N2	DI-TP (1) µg L^{-1}	DI-TP (2) µg L^{-1}	SCD	PCA axis 1 scores
1	30	6.45	181	184	0.78	-0.29
5	33	5.69	169	156	0.61	-0.43
10	31	4.31	168	157	0.75	-0.93
15	37	3.70	173	159	0.48	-1.02
20	37	5.90	161	146	0.57	-0.40
30	40	6.46	172	161	0.46	-0.24
40	36	12.26	133	123	0.53	1.52
50	37	9.96	115	102	0.31	0.97
60	42	12.48	132	128	0.20	0.64
70	40	7.08	134	128		0.17

5.4 Macrofossil analysis

5.4.1 Plant macrofossils

Ten samples were analysed for plant macrofossil remains in the SCM14C core (Table 17). A total of 12 taxa were observed in the core and a summary diagram for the major taxa is presented in Figure 30. The cluster analysis identified three zones in the plant macrofossil record. Unfortunately the marginal core from Comber Mere could not be dated by the SCP method and, therefore, the timing of changes in the macrofossil data cannot be determined.

Zone 1 (100-65 cm) was dominated by *Nymphaea alba* seed fragments and *Nymphaeaceae trichosclereids*. The blue green alga *Gleotrichia* spp. was also present, rising in abundance towards the top of Zone 1. *Chara* oospores ('oval' type) were present in the lower two samples of the core but in small numbers reaching a maximum of only 25 oospores per 100 cm^3 at 90 cm.

In Zone 2 (65-15 cm) *Nymphaea alba* seed fragments, *Nymphaeaceae trichosclereids* and *Gleotrichia* spp. were present in all samples. *Chara* oospores ('oval' type) were only found in small numbers in Zone 2 at 40 cm. Aquatic plant diversity increased towards the top of Zone 2 to eight taxa compared to three to five taxa in the lower core (Table 17), with increased abundances of *Nitella* oospores, *Alisma plantago-aquatica* seeds, *Potamogeton* seed fragments and *Ranunculus* sect. *Batrachium* seed fragments occurring at 30 cm and above.

Zone 3 (15-0 cm) comprised two samples which were dominated by *Potamogeton* cf. *natans* seeds and *Potamogeton* unidentified decayed seeds, along with low abundances of *Nymphaea alba* seed fragments and *Nymphaeaceae trichosclereids*. Hence, diversity declined.

Table 17 Results of the plant macrofossil analysis on SCM14C

Depth (cm)	No. of taxa	N2
2	5	1.58
10	4	2.69
20	8	3.74
30	6	2.46
40	4	1.72
50	3	2.17
60	4	2.50
70	4	2.84
90	4	1.88
100	5	1.12

5.4.2 Zooplankton ephippia

The cluster analysis identified three zones in the ephippia record (Figure 31).

In Zone 1 (100-50 cm) zooplankton ephippial remains were scarce with relatively low numbers of *Daphnia hyalina* agg. in all samples.

In Zone 2 (50-15 cm) *Ceriodaphnia* spp first occurred within the record at 40 cm and increased dramatically at the top of the zone in the 20 cm sample.

Zone 3 (15-0 cm) had the most abundant and diverse remains, with very high abundances of *Daphnia hyalina* agg., *Daphnia pulex* and the large-bodied pelagic species *Daphnia magna* present in relatively high numbers, particularly in the uppermost sample.

5.5 Cladocera analysis

Twelve samples were analysed for chitinous cladoceran remains in the SCM14B core (Table 18). A total of 26 taxa were observed in the core and a summary diagram for the major taxa is presented in Figure 32. Three zones were identified by cluster analysis.

In Zone 1 (100-65 cm, ~pre-1850) a total of 22 taxa were identified. The assemblage was dominated by the open-water species *Bosmina longirostris* (49-60% relative abundance) with *Bosmina coregoni*, *Chydorus sphaericus* and *Alona quadrangularis* present at around 5-10%. The relative abundance of 'rarer' taxa was typically less than 3%, but Zone 1 contained a diverse range of mud and plant-associated species.

In Zone 2 (65-7.5 cm, pre-1850 to ~1980) the abundance and diversity of the mud and plant-associated taxa decreased, while numbers of pelagic *B. longirostris* increased (51-73%).

In Zone 3 (7.5-0 cm, ~1980-2010) *B. longirostris* remained dominant. Chitinous remains of *Daphnia hyalina/longispina* agg. were also found in this zone, which corresponded with the increase in numbers of *Daphnia* species observed in the ephippia data (see section 5.4.2). The SCD scores were low throughout the core (<0.4) owing to the dominance of *B. longirostris* but were at their highest in Zone 3 owing to the appearance of *Daphnia hyalina/longispina* agg. and several other taxa not seen in the basal assemblages. The shifts in the PCA axis 1 scores accord with the changes in relative abundance of *B. longirostris*.

Table 18 Results of the Cladocera analysis on SCM14B

Depth (cm)	No. of taxa	N2	SCD	PCA axis 1 scores
0	20	2.50158	0.33	-0.55
5	18	2.5518	0.36	-0.76
10	20	2.13868	0.15	-0.63
15	21	2.45533	0.17	-0.22
20	18	2.25522	0.15	-0.48
30	16	1.84607	0.15	-1.15
40	17	3.18127	0.14	1.39
60	17	2.45455	0.08	-0.01
70	17	3.94583	0.11	1.13
80	16	3.21567	0.07	0.90
90	21	2.65116	0.09	-0.18
100	17	2.87283	0	0.55

5.6 Pigment analysis

Twelve samples were analysed for sedimentary pigments in the SCM14B core. A total of 12 chlorophylls and carotenoids were observed in the core and a summary diagram is presented in Figure 33. Four zones were identified by cluster analysis. The presence of degradation-prone pigments (fucoxanthin, Chl *a*, Chl *b*) and moderately high concentrations of pigments indicate that preservation of pigments was good.

Zone 1 (103-107 cm, ~pre-1850) comprised the basal core sample which had low-moderate concentrations of most pigments.

In Zone 2 (103-75 cm, ~pre-1850) pigment abundance remained similar to zone 1 except that echinenone was absent in zone 2, suggesting loss of some components of the cyanobacterial flora. Pheophytin *a* and *b* concentrations were variable which may indicate fluctuations in aquatic plant communities.

In Zone 3 (75-5 cm, ~pre 1850-1980) pigments from most algal groups increased slowly during this period indicating a steady rise in algal production. Once again pigments that may be associated with aquatic plants as well as chlorophytes (Chl *b*, pheophytin *b*, pheophytin *a*) deviated from this overall trend and varied throughout this zone, with maximal production ~1850.

Zone 4 (5-0 cm, ~1980-2010) showed an increase in most pigments, consistent with an increase in aquatic production. Echinenone declined during this period, however, suggesting changes in the composition of the cyanobacterial community relative to zone 3. While some of this increase may be caused by incomplete degradation of pigments in surface sediments, the consistent increase in other stable compounds suggests that there is an overall increase in primary production in this zone.

5.7 Application of macrophyte-nutrient models

Compared to the results obtained for Tatton and Melchett Meres the reconstruction for Comber Mere is unsatisfactory and suggests that perhaps the most recent upper part of the core is missing. From the base of the core there is a long period of stable nymphaeid dominated vegetation with the macrofossil reconstruction exhibiting a good match with the spatial analogue historical archive approach (Figure 34). However, there is a marked departure between the reconstruction based on the macrofossils in the upper part of the core, and the reconstruction based on the contemporary vegetation. The former has a reconstructed TP of just 42 while the latter is more than twice this value at 94 µg L^{-1}. Assuming the second value to be valid this translates to a realistic TP concentration of 317 (130 – 766) µg L^{-1} which is in reasonable agreement with the current measured annual mean concentration of 266 µg L^{-1}.

Probably the most useful and positive aspect of the Comber Mere core is the tie up between the macrofossil reconstruction at the base of the core and the spatial analogue approach based on historical records. These suggest that the historic baseline TP concentration for Comber Mere was 47 (20 – 112) µg L^{-1} (historical records from adjacent sites) or 54 (23 – 129) µg L^{-1} (macrofossils). There is thus fairly strong evidence to regard 50 µg L^{-1} TP as the reference TP concentration for this mere. The currently recorded (or predicted) concentrations therefore represent a five to six fold increase on this baseline value. The presence of *Zannichellia palustris*, *Potamogeton pusillus*, *Enteromorpha* and various lemnids alongside the usual nymphaeids in the contemporary vegetation is certainly suggestive of enrichment and there is no evidence from the macrofossils that such taxa were represented at this site in the past.

5.8 Discussion

The open water sediment core from Comber Mere extends back to ~1800 AD based on extrapolation of the SCD derived accumulation rates, although this chronology is rather speculative and should be treated with a degree of caution. Unfortunately the marginal core from the lake could not be dated by the SCP method and, therefore, the timing of the changes in the macrofossil data cannot be established.

The sediment core data indicate that Comber Mere was less nutrient-rich in the past than it is today. The diatom flora prior to ~1900 is typical of a productive, alkaline lake, containing species such as *Stephanodiscus parvus* and *Cyclostephanos dubius* typically seen in nutrient-rich waters. However, it also includes relatively large percentages of *Cyclotella radiosa* and *Stephanodiscus neoastraea* which are associated with lakes of intermediate nutrient concentrations, the latter also being observed in the bottom of the core from Tatton Mere. The early assemblages are comprised of roughly equal percentages of planktonic and non-planktonic taxa suggesting plentiful habitats for diatoms attached to plant, stone and mud surfaces and thereby implying a favourable light climate at this time. The diatom data are supported by the pigment data in which low to moderate concentrations of most pigments were recorded in the lower core samples, suggesting relatively low productivity. The macrofossil data suggest that the lake was dominated by nymphaeids in the past with high numbers of seeds and trichosclereids. Whilst *Chara* oospores were found at the bottom of the core, they were present in very low numbers (<30), so it is unlikely that charophytes were a key component of the vegetation, at least in the area of the lake from where the core was collected. The zooplankton data accord with the macrofossil data indicating presence of plants in the past as the early assemblages are diverse and contain numerous plant-associated species. In contrast to the deepwater core from Tatton Mere, where plant-associated Cladocera remains were sparse, it seems that the relative proximity of the deep basin to the lake shore in Comber Mere has resulted in better representation of both the pelagic and littoral Cladocera taxa in the latter site.

Marked changes were evident in the sediment record from ~1900 with eutrophication suggested across a range of indicators. The diatom data exhibit a notable disappearance of *Cyclotella radiosa* and a large decrease in *Stephanodiscus neoastraea* whilst *Stephanodiscus parvus* and *Stephanodiscus hantzschii* increase. The overall planktonic component of the diatom flora increases to ~70% by the early 1900s and DI-TP concentrations increase to ~170 µg L^{-1}. Similar species shifts have been observed in the palaeoecological record of Betton Pool (Brooks *et al.,* 2001) and Crose Mere (N.J. Anderson unpublished) as the lakes became progressively enriched. Interestingly, however, *Cyclotella ocellata*, the diatom that dominates the early assemblages of Betton and Crose Mere was seen in only negligible amounts in the Comber Mere core perhaps suggesting that our core does not extend back to true pre-enrichment conditions or it may be that these two Shropshire meres have a different baseline diatom flora than the Cheshire meres in the current study. In accordance with the diatom data, pigments from most algal groups increased slowly from the early 1900s indicating a steady rise in algal production. The macrofossil data indicate a decrease in the abundance of nymphaeids in the middle part of the record (date unknown) and particularly from ~20 cm and, therefore, there is a suggestion that the plant community was in decline during this period. Accordingly, the zooplankton data exhibit a decrease in plant-associated species from the mid-1850s with considerable declines from ~1900.

Further notable changes are seen in the sediment record from ~1950. There is an expansion of *Aulacoseira granulata* which is a late season diatom species, generally found in late summer to autumn. This may arise due to the decline in aquatic plant biomass and the decline in nymphaeids in particular, and hence opening up of the water column for algal growth. The DI-TP values continue to rise to a maximum value of ~180 µg L^{-1} at the surface which is in good agreement with the measured annual mean TP of 187 µg L^{-1} for the years 2005 to 2009 and suggest that the eutrophication trend has continued to the present day. The diatom-inferred values are consistently in excess of the CSM target limit of 50 µg L^{-1} for this lake type. The macrophyte-inferred TP values also provide fairly strong evidence to regard 50 µg L^{-1} TP as the reference TP concentration for Comber Mere. Similarly to the diatoms, the pigment data suggest an overall increase in primary production in the upper core, most notably from the mid-1900s. Indeed there are regular periods of high algal biomass (chlorophyll *a*) during summer in Comber Mere and there was evidence of a cyanobacterial bloom during plant surveys in July 2008 (Goldsmith, 2010).

Additionally there were marked changes in the chitinous zooplankton record suggesting a shift from littoral to plankton dominance with more open water and pelagic taxa found in the upper core. A notable feature is the increase in *Daphnia hyalina/longispina* agg. in the upper 5 cm of the open water core. This is further illustrated by the ephippia data where large-bodied *Daphnia* spp. increase markedly in the upper 15 cm of the littoral core, coincident with the decline in remains of nymphaeids. These shifts signal greater pelagic production. Indeed the combination of high abundance of *Bosmina longirostris* and the rise in *Daphnia* spp. is indicative of an increasing food source. Interestingly the relatively high abundance of *Chydorus sphaericus* in the upper core could reflect blue-green algal blooms, as it is a species that can do well in bloom conditions.

The macrofossil data suggest that the lake currently supports several pondweeds and some nymphaeids. This is in reasonable agreement with the plant survey carried out in 2008 by ENSIS Ltd (Goldsmith, 2010) which recorded *Potamogeton pusillus*, *P. crispus*, *Lemna minor* and *Chara globularis. Potamogeton pectinatus, Zannichellia palustris, Elodea canadensis, Nymphaea alba* and *Nuphar lutea* were also present. According to the site condition report (Goldsmith, 2010), despite the reasonable number of species, the aquatic macrophytes were generally rather sparse and restricted mostly to shallow water (<1.0 m) and to the western end of the site. Furthermore, there were many areas in the mere without any submerged species present and overall it was concluded that Comber Mere has a sparse and rather poor characteristic flora and is in unfavourable condition. Given the patchiness and scarcity

of aquatic vegetation in the lake it is very possible that our coring site, which lies towards the central-eastern part of the lake, reflects only the local plant community. In that case, several plants seen elsewhere in the lake are unlikely to be recorded in our core. Furthermore, the application of the macrophyte-nutrient model to the macrofossil data suggests that the most recent upper part of the core may be missing. While the difficulties of dating this core may lend some support to this it is more likely that the fluidity and unconsolidated nature of the upper sediments causes them to be subject to resuspension and hence difficult to capture at a reasonable resolution when coring.

In summary, the palaeoecological data indicate that Comber Mere has been a nutrient-rich lake for the whole of the period represented by the sediment core, i.e for approximately the last 200 years. Nevertheless the lake was less productive in the past and has experienced recent enrichment starting in ~1900, which has continued to the present day. The data suggest an increase in pelagic productivity and a decline in the plant community reflecting more eutrophic conditions than in the past (Vadeboncoeur *et al.,* 2003).

Figure 29 Summary diatom diagram of Comber Mere core, SCM14B

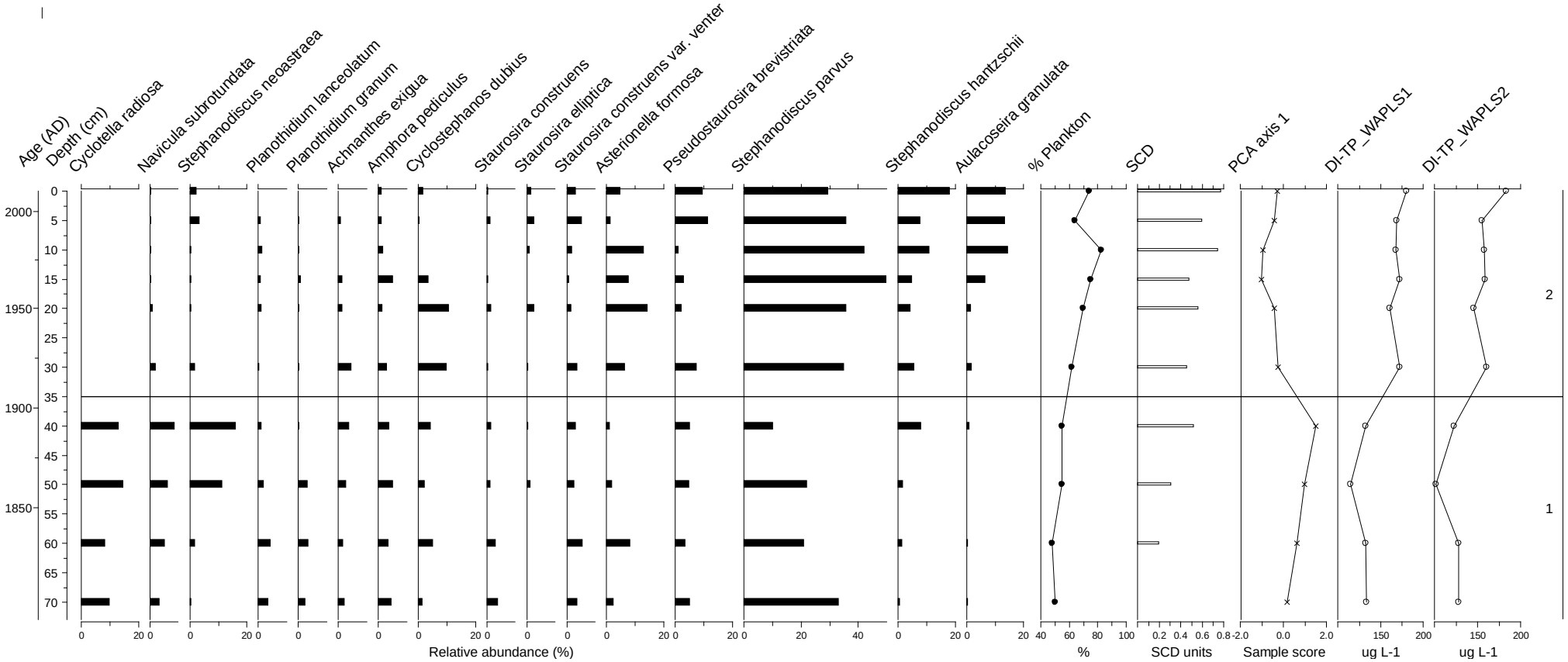


Figure 30 Summary plant macrofossil diagram of Comber Mere core, SCM14C

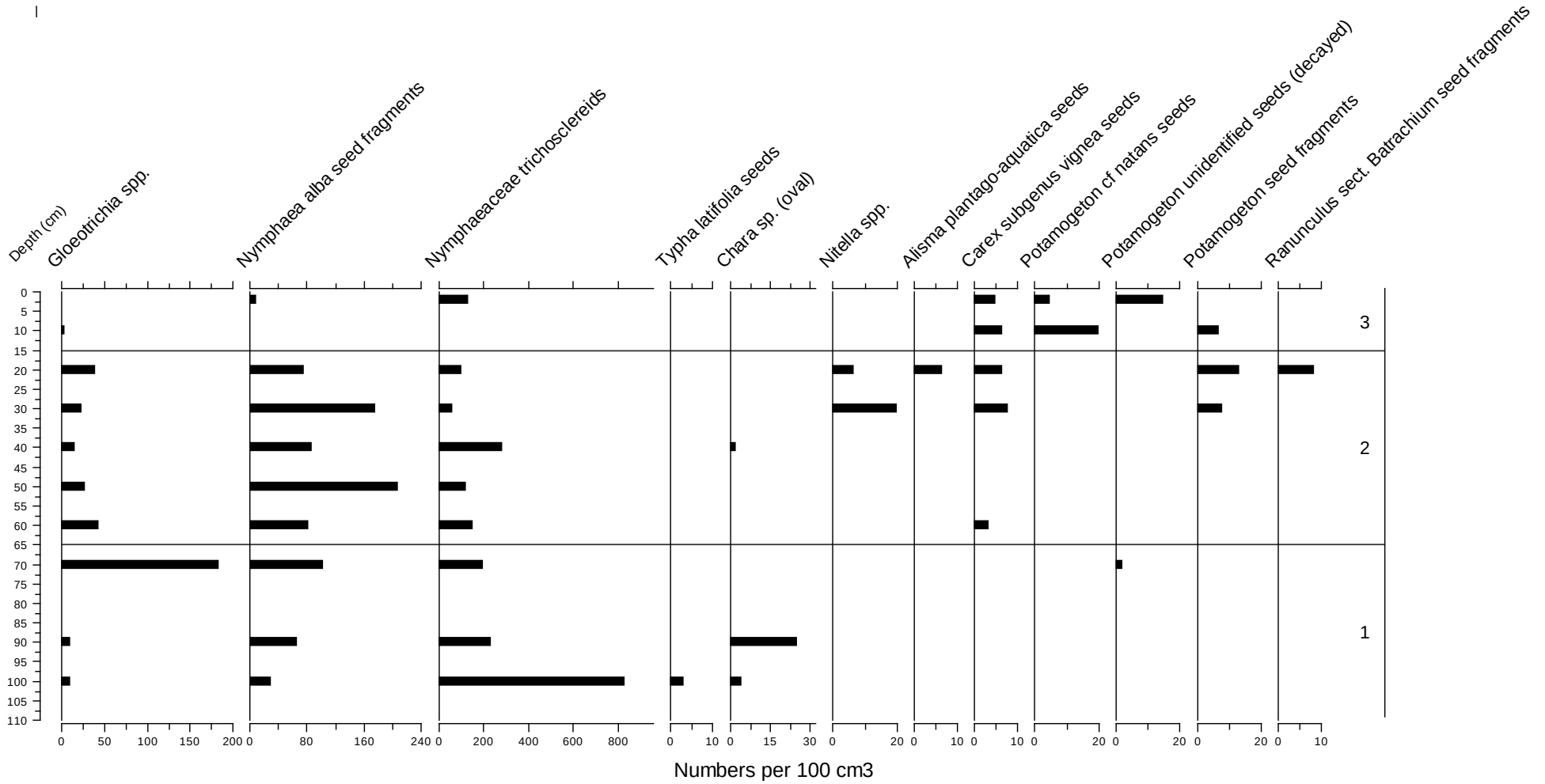


Figure 31 Summary zooplankton ephippia diagram of Comber Mere core, SCM14C

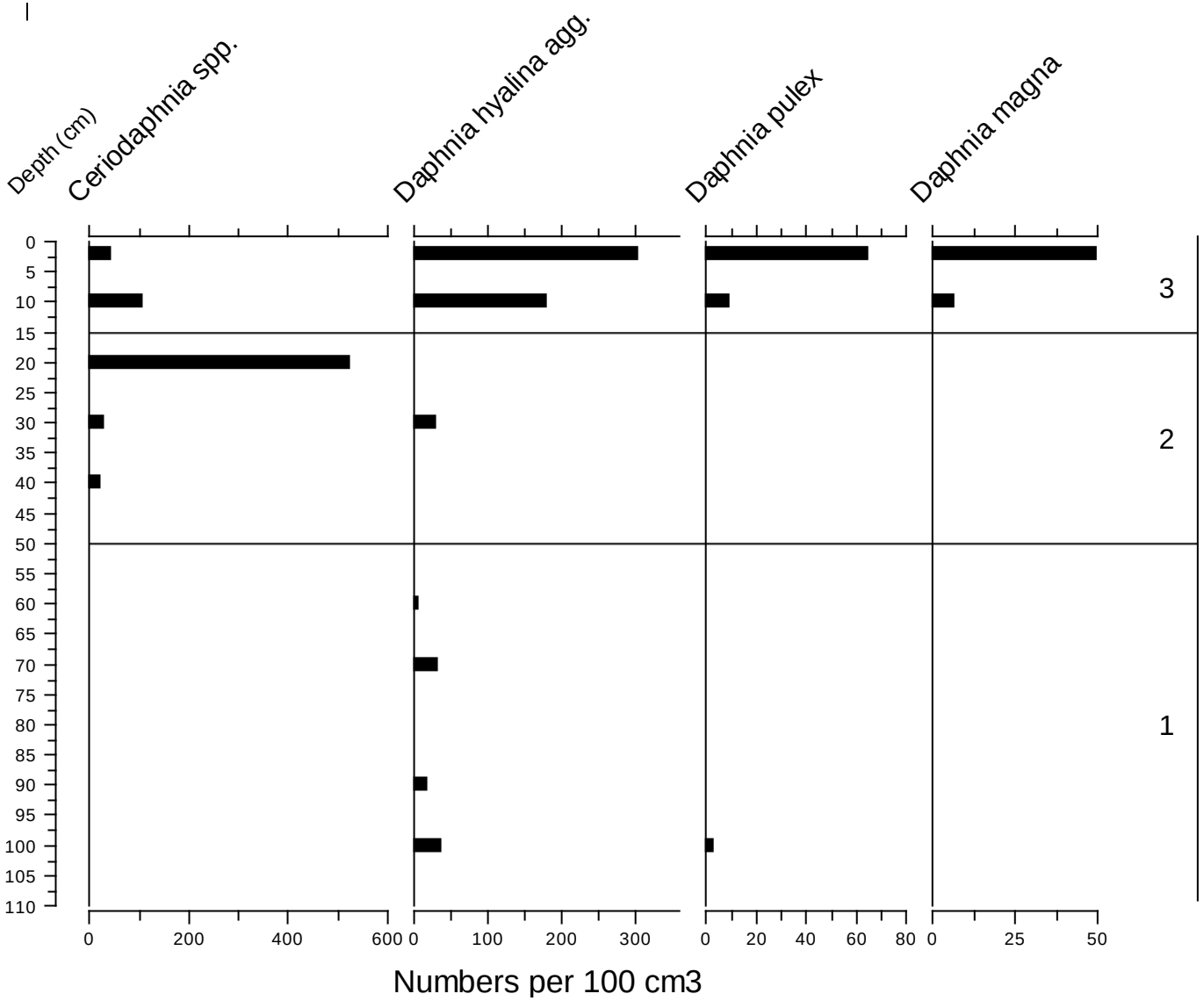


Figure 32 Summary Cladocera diagram of Comber Mere core, SCM14B

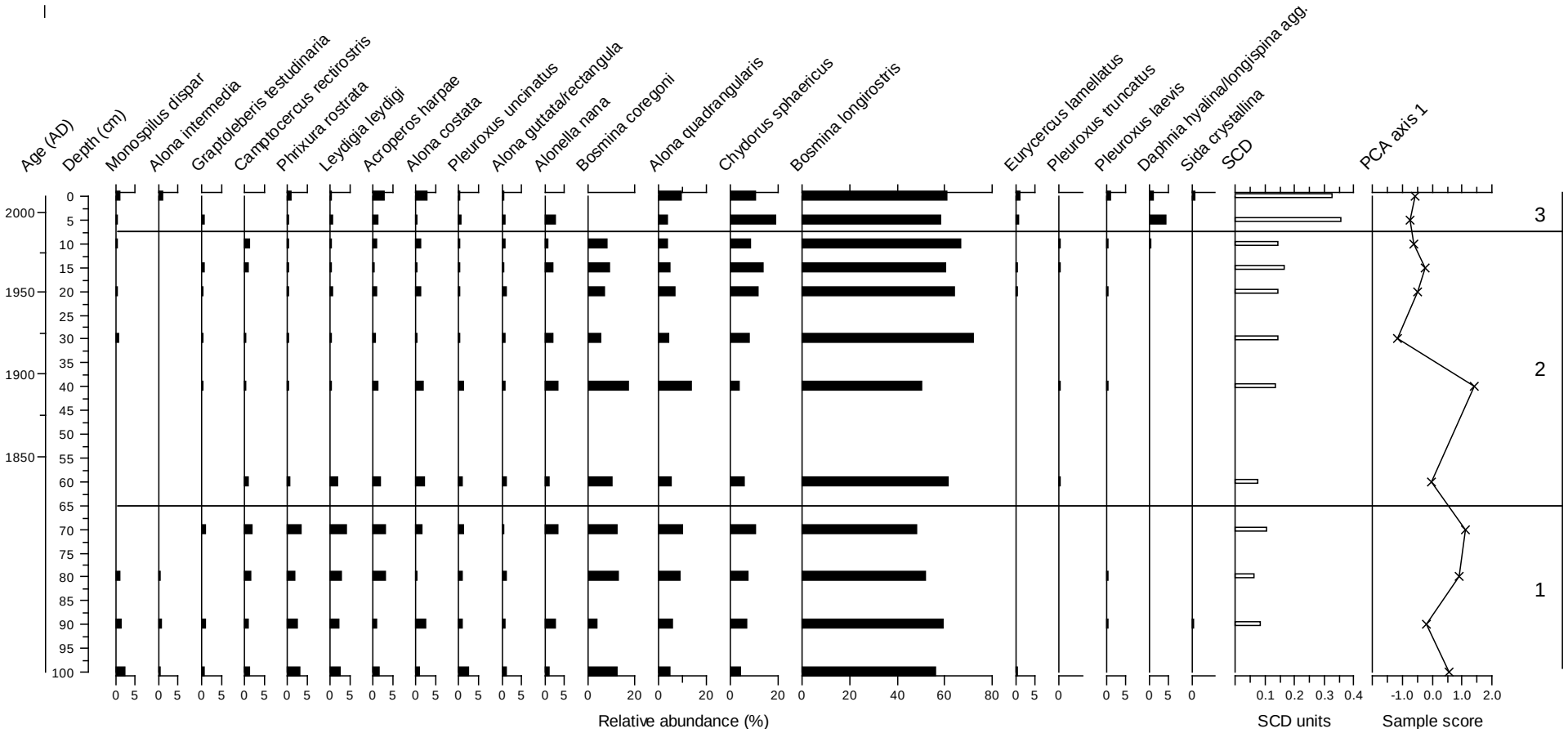


Figure 33 Summary pigment diagram of Comber Mere core, SCM14B
(note variable scaling on the x axes; pigment concentrations in nanomoles pigment per gram organic weight sediment)

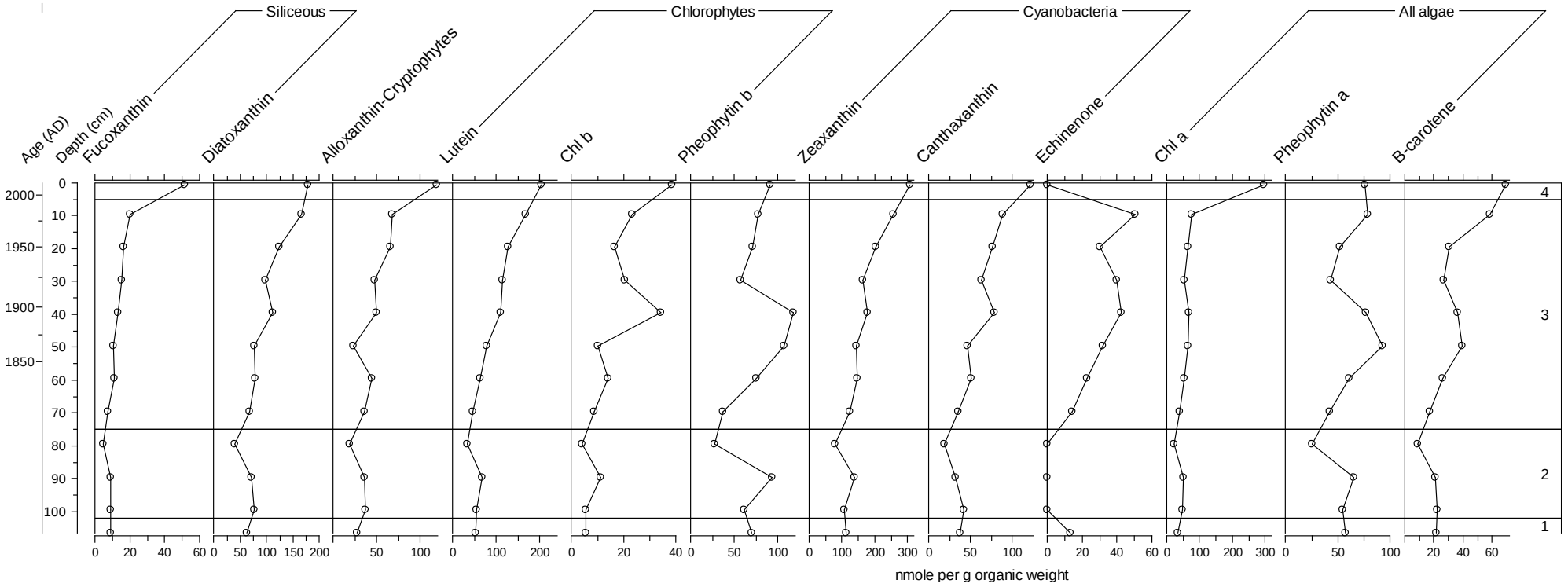
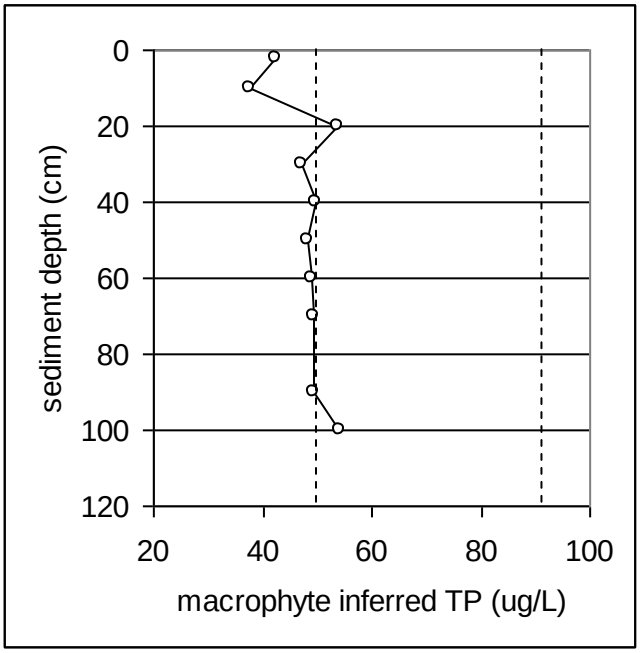


Figure 34 Macrophyte-inferred TP for Comber Mere



Note: Points indicate macrofossil based reconstructions. Left hand dotted line indicates reconstructed mid-1800 TP using spatial analogue approach with historical record data from adjacent meres. Right hand line indicates reconstructed TP using contemporary vegetation.

6. SUMMARY

6.1 Trophic histories

All three of the study sites have experienced enrichment over the period represented by the sediment records, most notably since around the mid-1900s. This has manifested itself in an increase in diatom taxa associated with nutrient-rich waters, an increase in the diversity of diatom plankton and consequent extension of the period of planktonic algal growth, an increase in pelagic zooplankton and concomitant decline in those associated with plants, an increase in pigment concentrations and changes in pheophytin b when plants decline, and a decline in plant diversity and structural changes in the plant community (see section 6.2). In all cases the palaeoecological data indicate an increase in pelagic productivity over time reflecting more eutrophic conditions than in the past (e.g. Vadeboncoeur *et al.,* 2003).

The interpretation of the Melchett Mere data is complicated by the recent and somewhat unusual site origin which results in uncertainties in the early part of the record over the amount of observed change that can be explained by increasing water depth and the amount that can be attributed to increases in nutrient loading. Nonetheless there has been an increase in pelagic productivity since approximately the mid-1900s, with major increases in large-bodied zooplankton species in particular, which is indicative of enrichment. According to Moss *et al*. (1992) Melchett Mere is primarily groundwater fed with some inputs from precipitation and diffuse overland flow. It is possible, therefore, that the enrichment of the adjacent Tatton Mere which lies to the south led to local groundwater enrichment and thus enhanced the fertility of Melchett Mere. Diffuse nutrient inputs from the surrounding parkland are also likely (ECUS, 2001a).

For Tatton Mere, the study indicates enrichment since around the early 1800s, which has continued through the twentieth century. Interestingly Tatton Mere appears to have been nutrient-rich for the 200 year period represented by the sediment cores. There has been much debate over whether the meres are indeed naturally rich systems owing to the P-rich drift deposits in the region or whether in fact they have simply been impacted over long timescales (Anderson, 1995). Several long term palaeolimnological studies provide evidence of anthropogenically induced eutrophication dating back to at least Medieval times (see Anderson, 1995) whilst sediment studies focusing on the last few hundred years indicate a period of enhanced productivity associated with intensification of agriculture during the 20th century (e.g. Brooks *et al.,* 2001). Given the long history of impact in the region, it would seem that our 200 year record of Tatton Mere is insufficient to capture the true pre-enrichment baseline conditions. Nevertheless even within the last two centuries there is clear evidence of enrichment leading us to conclude that whilst Tatton Mere may well have been relatively nutrient-rich in the past it has clearly undergone a period of recent cultural eutrophication. Moss *et al*. (1992) discuss the possibility of entry of sewage effluent to Tatton Mere from the nearby town of Knutsford as being a source of nutrients to the lake, as the lake is fed by one main surface inflow (River Lilley) which originates within the town. Road runoff is also likely to enter the lake via this inflow. Diffuse sources of nutrients from agriculture within the SSSI are likely to be relatively minor given that the lake is part of a highly managed estate and deer park with relatively extensive livestock grazing, although inputs from arable land beyond the SSSI may have an influence on the lake as there is approximately 43 hectares of arable land in the catchment (ECUS, 2001a). Another possible source of nutrients is nitrogen from industrial activities in the neighbouring city of Manchester (e.g. Curtis *et al*., 2000) but this is entirely speculative.

In the uppermost samples of the Tatton Mere core there is a possible hint of water quality improvement across several indicators with a decline in diatom taxa associated with highly nutrient-rich lakes, an increase in *Chara* remains and a decline in pigment concentrations. In the absence of information on any potential reductions in nutrient sources it is not possible to determine whether these changes are a result of bottom up or top down factors. Data on

nutrient loads and fish populations would be required in order to fully explore the causes of these recent changes in the ecosystem. Nevertheless the *Daphnia* data suggest that the absence of top-down grazing by fish has been at least partly responsible for the recent improvements. If this is indeed the case then any further recovery could be confounded by future changes in the fish community. In Lake Sobygaard in Denmark nutrient reduction has led to a recovery in the fish populations and has thereby increased predation pressure on the zooplankton leading to their decline and hence releasing grazing control on the phytoplankton (Davidson, pers. comm.). Additionally it is possible that the observed changes may reflect improvements in sewage treatment, expansion of mains sewerage, and reduction or better maintenance of septic tanks, but further research is needed to explore if this is the case.

Similarly to Tatton Mere, the palaeoecological data indicate that Comber Mere has been a nutrient-rich lake for the 200 year period represented by the sediment core. The stability of the diatom flora prior to ~1900 in the Comber Mere core suggests that whilst we may not have extended the record back far enough to establish true pre-enrichment conditions we have at least reached a point in the past when conditions were less productive than today and, therefore, the data can be used to inform restoration targets. The data suggest that Comber Mere has experienced enrichment since ~1900, which has continued to the present day. There is no evidence of water quality improvement at Comber Mere. Moss *et al*. (1992) reported an increase in cattle and pig numbers in the catchment between 1931 and 1987 as well as a marked loss of land to non-agricultural uses. The catchment today is comprised primarily of agricultural land including arable (183 hectares) and improved pasture (360 hectares) (ECUS, 2001b). It is highly likely, therefore, that enrichment of the lake has been brought about by increased nutrient loading from agriculture. The lake is fed by two main stream inflows and water chemistry data from the more substantial of these in the south-west led Moss *et al*. (1992) to suggest that an upstream livestock (dairy) farm might be the major nutrient source to the lake. A report on Comber Mere by ECUS (2001b) also states that the main inflow has been identified as being periodically enriched with agricultural runoff from the farm upstream. In the absence of a catchment survey the current study is unable to provide any evidence of whether this is still the case today. It should be noted that there is an outlet control on Comber Mere which could possibly be a factor in increasing residence time, which in turn would lengthen the time available for algae to take up nutrients from the water column and hence may exacerbate algal growth.

It is interesting to note the apparent stability of both Tatton and Comber Mere in the past despite the high nutrient concentrations. The major ecological shifts appear to occur in the twentieth century with the onset of more intensive agriculture and/or greater inputs of sewage from expanding populations in the catchments. A switch in the N:P ratio is likely to have driven this process as more P has become available. The data suggest, therefore, that the sites exhibited healthy ecosystem functioning in the past which has since deteriorated as a result of recent enrichment.

6.2 Changes in the plant communities

In the Melchett Mere core macrofossil remains were relatively sparse and aquatic species diversity was low. This arose because macrofossil analysis was carried out on a core collected from the deep basin of the site (in a depth of ~11 m) where plants would not have been growing *in situ*. In previous studies, macrofossil analysis has been undertaken on cores from marginal, shallow water zones in the proximity of plant beds as abundance and diversity of macrofossils are greater in marginal than deepwater areas. This is because heavy remains such as seeds do not travel far from their source plant (Davidson *et al*., 2005; Zhao *et al*., 2006). Unfortunately intact marginal sediments could not be retrieved from Melchett Mere. Therefore it was not possible to assess changes in the plant community of the lake with any confidence. What we can say is that aquatic plants have always been present at

the site and there is a tentative suggestion that there might have been a shift from *Chara* to *Potamogeton* taxa, which would be consistent with eutrophication.

In Tatton Mere, the macrofossil record allowed the dynamics of the aquatic vegetation over approximately the last 250 years to be assessed. The flora was structurally diverse in the early period of the core comprising several taxa associated with lakes of moderate productivity such as *Menyanthes trifoliata, Myriophyllum* spp., a number of *Chara* taxa, *Ranunculus* sect. *Batrachium, Potamogeton* cf. *natans* and *Potamogeton obtusifolius*. The first observed shifts in the mid-1800s saw a decrease in *Chara* spp., disappearance of *Menyanthes trifoliata, Myriophyllum* spp. *Potamogeton* cf. *natans* and *Potamogeton obtusifolius* seeds, an increase in nymphaeids, and appearance of *Nitella* spp. and fine-leaved *Potamogeton* spp., signalling a shift towards a more eutrophic flora. The next point of change in the plant macrofossil record occurred at ~1960 when there was a marked decline in *Nymphaea* remains and *Nitella* spp. and an increase in *Callitriche* spp. and *Zannichellia palustris*. These species shifts, most notably the decline in Charophytes and increase in fine-leaved *Potamogeton* spp., *Zannichellia palustris* and *Callitriche,* appear to be a common feature of lowland lakes exhibiting signs of enrichment (e.g. Blindow, 1992; Davidson *et al.,* 2008; Sayer *et al.,* 2010). Hence the most likely explanation for the changes is nutrient enrichment. There is some evidence from other lakes, however, that changes in abundance of macroinvertebrates mediated by fish kills can cause big switches in aquatic plant composition (e.g. Amsinck *et al*., 2005) but there is no strong evidence from our zooplankton data, or from the limited information on fish populations in the lake, to suggest that fish kills have been a regular feature in the last 50 years. The floristic changes also have implications for the duration of the plant dominated period as discussed above. Hence we see the replacement of a structurally diverse flora with abundant Charophytes, nymphaeids and taxa with a mix of seasonalities to a less diverse flora comprised of largely nutrient-rich taxa that dominate in the early part of the growing season. The slight increase in *Chara* remains in the uppermost sediments may signal an improvement in water quality and, therefore, continued monitoring is recommended. The information on the pre-enrichment flora and plant dynamics over the last few centuries should prove valuable for setting targets for future management of Tatton Mere.

Unfortunately the marginal core from Comber Mere could not be dated and, therefore, the timing of changes in the macrofossil record cannot be determined. Additionally the aquatic vegetation in the lake is spatially restricted and scarce and it is likely, therefore, that our core is representative of the local plant community and not of the site as a whole. Nonetheless, the macrofossil data suggest that the lake was dominated by nymphaeids in the past and that their abundance declined in the middle part of the record. The macrofossil data suggest that the lake currently supports several pondweeds and some nymphaeids which is in reasonable agreement with recent plant survey data. The decline in the plant community is most likely a result of progressive enrichment of the site as discussed in section 6.1.

6.3 Implications for management

The study suggests that there may be signs of water quality improvement at Tatton Mere. However this is based on only one or two samples in the upper cores and thus continued monitoring of the nutrient chemistry, algal populations and the plant community of the site is recommended to see if recent signs of improvement are sustained. At the time of reporting very little information on the management history of the site was available and, therefore, it is not known whether any specific restoration plans or remediation actions have been implemented to bring about the improvements inferred from the palaeoecological data. Notes provided by Natural England indicate that modifications were made to the Tatton Mere Dam in 2004 which involved the raising of the crest of the dam by 0.5 m. This may have reduced the residence time of the lake thereby allowing nutrients to be more rapidly flushed from the system but data were not available to confirm or otherwise. The only other remedial work of note in the information provided by Natural England is the construction of drainage ditches

along a pathway in 2001 to intercept overland flow. While this may have reduced runoff to some extent it is unlikely that this has had a major role in improving water quality. Clearly if management plans have been in place then they appear to have met with a degree of success and thus a continuation of these measures is advised. The continued reduction of nutrient input from both point and diffuse sources, where they still exist, is recommended. If direct runoff from agricultural land is deemed to be an issue then the creation of buffer strips around the mere should reduce both nutrient and silt loading.

Tatton Mere is fished and high densities of fish were present in the lake in 2000 including pike and roach (Hateley, 2000). The lake is known to support benthic fish including carp, tench and bream. ECUS (2001a) report that "fish populations are thought to have increased in recent years" and consequently recommend that "no enhancement of zooplanktivorous/benthivorous fish stocks is undertaken in future". Unfortunately, there is a lack of more recent data on the fish community but according to information supplied by Natural England there is currently no consent for further stocking. The high numbers of *Daphnia magna* recorded in the recent sediments suggest that zooplantivory in the system is low as this species performs badly in the presence of fish. It is crucial to maintain low fish predation pressure so that *Daphnia* numbers remain high and thereby control the algal population. Any further recovery of the lake could be confounded by future changes in the fish community (see section 6.1). Interestingly, a large fish kill (~300 fish) occurred at Tatton Mere in July 2009 which was attributed to natural causes. It is unlikely that this very recent event has been registered in the sediment record yet. Nevertheless, the *Daphnia magna* increase seen in the uppermost sediments suggests that there may have been a number of minor fish kills in the past, or perhaps simply a lack of recruitment success. High pH from very intense algal blooms as well as low oxygen is known to cause the abrupt loss of small fish, in particular.

Given the close proximity of Melchett Mere to Tatton Mere it is likely that any improvements to the latter may also have some positive influence on the condition of the former. Clearly any management plan needs to encompass the whole SSSI and thus both waterbodies. While nutrient concentrations are currently considerably lower in Melchett Mere than in Tatton Mere monitoring of nutrients, as well as regular surveys of the plants and algae, of Melchett Mere is recommended to detect any changes in water quality.

There is no such evidence of water quality improvement at Comber Mere and at the time of reporting the current nutrient sources to the lake were not known, other than those documented by Moss *et al.* (1992) and ECUS (2001b) as discussed in section 6.1. A nutrient budget is recommended to identify the main sources of nutrients to the lake. Management should focus on reduction of external nutrients at a catchment scale. If sources of pollution from agriculture are indeed identified as the key problem then promotion of catchment sensitive farming to reduce runoff to a minimum is required. ECUS (2001b) report that the Combermere Estate Farm recently changed to organic methods so this may also have some positive impacts on nutrient loads. In the shallow water zones of the lake, internal loading may also be a concern as high nutrient inputs to the site over the last few hundred years will have resulted in accumulation of P in the sediments which can be released back to the water column during periods of anoxia. Indeed, Environment Agency data indicate release in autumn and winter following breakdown of the thermocline (ECUS, 2001b). Further research into the nature of P release from the sediments may be worthwhile. Monitoring of Comber Mere is important in order to obtain information on seasonal and inter-annual variation including chemical and biological parameters, crucially phytoplankton biomass (and composition if possible), zooplankton, macrophyte and fish populations.

Limited information provided by Natural England reports that Comber Mere is fished and fish stocks have been actively managed for a number of years with high densities of fish present in 2000 (Hateley, 2000). ECUS (2001b) report that roach, perch and pike are the main species and that there has been successful recruitment of fish in recent years, particularly bream. However, more recent data on the structure of the fish community is required in order

to make any recommendations on how the fish populations might be managed. As for Tatton Mere, the high numbers of *Daphnia* recorded in the recent sediments, and also reported by Moss *et al.* (1992), suggest that currently fish predation pressure is relatively low. It is important to prevent an increase in zooplanktivory as the high *Daphnia* numbers are likely to be a key factor in limiting the planktonic algal crop size. Moss *et al.* (1992) concluded that fish stocking be avoided and our data also lead us to this recommendation.

The information on past plant and animal communities of the lakes provided by the current study can be used to set targets for the sites and to assess the degree of recovery.

6.4 Recommendations for further work

The study has successfully determined the past plant and animal communities of the three study lakes and the degree to which these have changed over approximately the last 200 years. However, there were several limitations to this study which could be overcome by further work. Additionally the study has raised a number of questions which could be explored in future. Several recommendations for future work are listed below:

1. The retrieval of longer cores is recommended from Tatton Mere and Comber Mere to extend the records back beyond 200 years and enable the pre-enrichment communities of the lakes to be determined. This is particularly important for Tatton Mere as the current study was unable to fully establish the nature of the baseline diatom assemblages.

2. Higher resolution analysis of the existing sediment cores is recommended for periods identified as undergoing the greatest change. In the case of Tatton Mere and Comber Mere a focus on the last 50 years is recommended.

3. Interpretation of the data in the current study was limited by the lack of information on the study sites. Further research on the site histories is recommended to explore changes in land use, catchment events, nutrient sources, fish populations and any management activity.

4. A nutrient budget to identify the major nutrient sources to the lakes is recommended. A follow up to the comprehensive study by Moss *et al.* (1992) would provide valuable information that could be compared with the 1990s dataset to assess changes over the last 20 years.

5. Monitoring of chemical and biological parameters is recommended at all sites. Biological monitoring should include phytoplankton biomass (and composition if possible), zooplankton, macrophyte and fish populations. At Tatton Mere this will help to establish whether the lake is continuing on a trajectory of improvement.

6. Further research into the nature of P release from the sediments of Comber Mere may be worthwhile.

6.4.1 Using the sediment record to inform Common Standards Monitoring and lake condition assessment

The site condition of over sixty SSSI lakes has recently been assessed by ENSIS (NE Contract SAE03-02-320) based on their current macrophyte flora and nutrient status. The lakes listed in Table 19 were all classified as being in unfavourable condition due to a failure to either meet the floristic or water quality targets (or both) as defined within the Common Standards Monitoring Guidance for Standing Waters (JNCC, 2005). While most of these sites have clearly deteriorated over the past ~100 years, the extent to which they have declined in quality is often not known and hence restoration targets tend to be generic for the region and lake type, rather than informed from site specific records. Some sites may never have had the species present that are deemed necessary to comply with the required

targets, and while attempts are made to account for this within the CSM assessments, it is often purely speculative rather than based on any factual information. The Mere at Mere, for example, is classified as a mesotrophic lake and, therefore, should have an isoetid flora (a minimum of *Littorella uniflora*) and at least eight 'characteristic' mesotrophic species to be in favourable condition. For a small site like Mere Mere, while it is well known to have once had a more diverse flora, it is debatable whether it has ever achieved the full list of species necessary to classify it as 'favourable'. In the absence of historical data, palaeolimnological techniques can provide a valuable tool for defining a range of baseline data to aid the setting of restoration targets and to inform site management (Bennion *et al.,* 2010). In addition to better understanding the past plant communities and other biological components (e.g. algae, zooplankton) at a site, palaeoecological data can also be used to model the trends in nutrient status and hence set realistic chemical targets. Furthermore, the ability to view these changes within a dated timeframe can lead to a better understanding of the causes of the decline (e.g. changes in land management, fish stocking, sewage effluent or industrial development), and hence inform future management and aid long-term recovery.

Comber Mere, in the current study, is a good example of where palaeoecological analysis can be used to inform the site condition. Today, the site is hyper-eutrophic and relatively species poor and is, therefore, classed as unfavourable when assessed against the generic CSM guidelines for eutrophic lakes. Multi-proxy analysis of the sediments shows the site to have been nutrient-rich for at least 200 years and while there has undoubtedly been a steady decline in water quality over the past ~100 years, the aquatic flora does not appear to have been particularly diverse even prior to the decline, and the mere has had relatively high algal biomass for at least a century. It seems unlikely that Comber Mere ever supported six 'characteristic' eutrophic species at any one time over the past 200 years and the site would have been unfavourable in 1810, just as it is in 2010, when assessed within the CSM guidance. More realistic restoration targets can, therefore, be set with this information in mind such as reduction of nutrient inputs with the target being reduction of algal biomass, improved water clarity and healthy populations of the several pondweeds and nymphaeids that are present today.

Table 19 List of SSSI Lakes in 'unfavourable condition' where palaeoecological analysis might help inform conservation objectives

Lake	WBID	Grid Reference
Aqualate Mere	35724	SJ772204
Bar Mere	34328	SJ536478
Brasside Pond	28686	NZ292453
Broomlee Lough	28172	NY790697
Chapel Mere	34162	SJ539518
Crag Lough	28220	NY766679
Crose Mere	35211	SJ430305
Greenlee Lough	28165	NY770696
Hatch Mere	33210	SJ552721
Loe Pool	46556	SW648248
Malham Tarn	29844	SD893667
Norbury Meres	34260	SJ559493
Oss Mere	34545	SJ566438
Quoisley Meres	34438	SJ549455
Rostherne Mere	32650	SJ744842
Shibdon Pond	28314	NZ194628
Stanford Water	37309	TL860950
Tabley Mere	32960	SJ723769
Tabley Moat	32960	SJ723769
The Mere	32744	SJ732818

7. REFERENCES

Alonso, M. (1996) Crustacea. Branchiopoda. *Fauna Iberica*. Vol. 7. In *Museo Nacional de Ciencias Naturales CSIC* (eds M.A. Ramos *et al.*), pp. 486. Madrid.

Amsinck S., Jeppesen E. & Landkildehus F. (2005) Inference of past changes in zooplankton community structure and planktivorous fish abundance from sedimentary subfossils-a study of a coastal lake subjected to major fish kill incidents during the past century. *Archiv für Hydrobiologie,* **162,** 363-382.

Anderson, N.J. (1995) Naturally eutrophic lakes: reality, myth or myopia? *Trends in Ecology and Evolution*, **10**, 137-138.

Anderson, N. J., Rippey, B. & Gibson, C.E. (1993) A comparison of sedimentary and diatom-inferred phosphorus profiles: implications for defining pre-disturbance nutrient conditions. *Hydrobiologia,* **253**, 357-366.

Battarbee R.W., Jones V.J., Flower R.J., Cameron N.G., Bennion H., Carvalho L. & Juggins S. (2001) Diatoms. In: *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators* (eds J.P.Smol, H.J.B. Birks & W.M. Last), pp. 155-202. Kluwer Academic Publishers, Dordrecht, The Netherlands

Bennion, H. (1994) A diatom-phosphorus transfer function for shallow, eutrophic ponds in south-east England. *Hydrobiologia,* **275/6**, 391-410.

Bennion, H., Juggins, S. & Anderson, N. J. (1996) Predicting epilimnetic phosphorus concentrations using an improved diatom-based transfer function and its application to lake eutrophication management. *Environmental Science and Technology*, **30**, 2004-2007.

Bennion, H.B., Fluin, J. & Simpson, G.L. (2004) Assessing eutrophication and reference conditions for Scottish freshwater lochs using subfossil diatoms. *Journal of Applied Ecology,* **41**,124-138.

Bennion, H., Rawcliffe, R., Burgess, A., Clarke, G., Davidson, T., Rose, C., Rose, N, Sayer, C., & Turner, S. (2009) *Using novel palaeolimnological techniques to define lake conservation objectives. Final Report to Natural England*. Natural England Commissioned Report No. 22.

Bennion, H., Battarbee, R. W., Sayer, C. D., Simpson, G. L., Davidson, T. A. (2010) Defining reference conditions and restoration targets for lake ecosystems using palaeolimnology: a synthesis. *Journal of Paleolimnology*, in press.

Birks H.H. (2001) Plant Macrofossils. In: Smol J.P., Birks H.J.B., and Last W.M. (eds), *Tracking Environmental Change Using Lake Sediments.* Volume 3: Terrestrial, Algal, and Siliceous Indicators, pp. 49-74. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Birks, H.J.B. (1998) Numerical tools in palaeolimnology - progress, potentialities, and problems. *Journal of Paleolimnology,* **20**, 307-332.

Blindow I. (1992) Decline of charophytes during eutrophication: comparison with angiosperms. *Freshwater Biology,* **28,** 9-14.

Brooks, S.J., Bennion, H. & Birks, H.J.B. (2001) Tracing lake trophic history with a chironomid-total phosphorus inference model *Freshwater Biology,* **46**, 511-532.

Curtis, C.J., Allott, T.E.H., Hall, J., Harriman, R., Kernan, M., Reynolds, B. & Ullyet, J.M. (2000) Critical loads of sulphur and nitrogen for freshwaters in Great Britain and assessment

of deposition reduction requirements with the First-Order Acidity Balance (FAB) Model. *Hydrology and Earth Systems Sciences* **4**, 125-140.

Davidson, T., Sayer, C., Bennion, H.B., David, C., Rose, N. & Wade, M. (2005) A 250 year comparison of historical, macrofossil and pollen records of aquatic plants in a shallow lake. *Freshwater Biology,* **50**,1671-1686.

Davidson, T.A., Sayer, C.D., Perrow, M.R., Bramm, M. & Jeppesen, E. (2007) Are the controls of species composition similar for contemporary and sub-fossil cladoceran assemblages? A study of 39 shallow lakes of contrasting trophic status. *Journal of Paleolimnology,* **38**,117-134.

Davidson, T.A., Clarke, G.H., Morley, D., Rose, N., Turner, S. & Sayer, C.D. (2008) Palaeoecological investigation of the past biological structure and function of the Trinity Broads. ECRC Research Report No 122.

Davidson, T.A., Sayer, C.D., Perrow, M., Bramm, M., Jeppesen, E. (2010) The simultaneous inference of zooplanktivorous fish and macrophyte density from sub-fossil cladoceran assemblages: a multivariate regression tree approach. *Freshwater Biology,* **55**, 546-564.

Dean W.E. (Jr.) (1974) Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss-on-ignition: comparison with other methods. *Journal of Sedimentary Petrology,* **44**, 242-248.

ECUS (2001a) Meres and Mosses Conservation Plans: Tatton Meres. Report to English Nature and the Environment Agency.

ECUS (2001b) Meres and Mosses Conservation Plans: Comber Mere. Report to English Nature and the Environment Agency.

Flössner, D. (1972). Krebstiere. Crustacea. Kiemen- und Blattfusser. Branchiopoda. Fishlause. Brachiura. *Die Tierwelt Deutschland*. 60. Jena, Gustav Fisher Verlag, pp 1-501.

Frey, D.G. (1958). The late-glacial cladoceran fauna of a small lake. *Archiv für Hydrobiol*ogie, **54**, 209-275.

Frey, D.G. (1959). The taxonomic and phylogenetic significance of the head pores of the Chydoridae (Cladocera). *International Review of Hydrobiology*, **44**, 27-50.

Goldsmith, B. (2010). Lake SSSI condition assessment: compilation and interpretation of 2007-2009 data. In prep, Natural England Contract No: SAE03-02-320

Grimm, E.C. (1987). CONISS: A Fortran 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computer and Geosciences,* **13**, 13-35.

Grimm, E.C. (2004). TGView version 2.0.2. Illinois State Museum, Springfield, USA.

Hateley, J. (2000). Fisheries Hydroacoustic Surveys of Tatton Mere and Combermere, 24th July and 8th August 2000. Environment Agency Report.

Hill, M.O. & Gauch, H.G. (1980). Detrended correspondence analysis, an improved ordination technique. *Vegetatio,* **42**, 47-58.

Heiri, O., Lotter, A.F. & Lemcke, G. (2001) Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology,* **25**,101-110.

Jeppesen, E. (1998). The historical development in nutrient levels and trophic structure. (Jeppesen E. DSc). *NERI Technical Report, No. 247*, 37-39.

Jeppesen, E., Madsen E.A & Jensen J.P. (1996) Reconstructing the past density of planktivorous fish from sedimentary zooplankton fossils: a surface sediment calibration data set from shallow lakes. *Freshwater Biology*, **36**, 115-127.

Jeppesen E., Leavitt P., De Meester L. & Jensen J.P. (2001) Functional ecology and palaeolimnology: using cladoceran remains to reconstruct anthropogenic impact. *Trends in Ecology and Evolution,* **16**, 191-198.

Joint Nature Conservation Committee (JNCC) (2005) Common Standards Monitoring Guidance for Standing Waters Version March 2005. JNCC Report, JNCC, Peterborough.

Juggins. S. (1991). ZONE version 1.2 User guide. University of Newcastle, Newcastle upon Tyne, UK.

Juggins, S. (2003). C^2 User guide. Software for ecological and palaeoecological data analysis and visualisation. University of Newcastle, Newcastle upon Tyne, UK, 69 pp.

Korhola, A. & Rautio, M. (2001). Cladocera and other branchiopod crustaceans. In *Tracking Environmental Change Using Lake Sediments. Vol. 4: Zoological Indicators* (eds J.P Smol, H.J.B. Birks & W.M. Last), pp.5-41. Kluwer Academic Publishers, Dordrecht.

Krammer, K. & Lange-Bertalot, H. (1986-1991) Bacillariophyceae. 1-4 Teil. *Süsswasserflora von Mitteleuropa* (eds H. Ettl, J. Gerloff, H. Heynig & D. Mollenhauer). Gustav Fischer Verlag, Stuttgart.

Lockton, A., Whild, S & Hodgetts, N. (2001) *A Botanical Survey of Cheshire Meres and Mosses in 2001*. English Nature, Shrewsbury.

Lowe J.J. & Walker M.J.C. (1997). *Reconstructing Quaternary Environments* (2nd ed.). Prentice Hall, London.

McGowan, S., G. Britton, E.Y. Haworth & B. Moss (1999). Ancient blue-green blooms *Limnology and Oceanogr*aphy, **44**, 436-439.

McGowan, S., P.R. Leavit R.I. Hall, N.J. Anderson, E. Jeppesen & B.V. Odgaard. (2005). Controls of algal abundance and community composition during ecosystem state change. *Ecology,* **86**, 2200-2211.

McGowan, S. (2007). Pigments in sediments of aquatic environments. In: Elias, S. (ed.) *Encyclopedia of Quaternary Sciences*. Elsevier.

Moss B., McGowan, S., Kilinc S. & Carvalho, L. (1992) Current limnological condition of a group of the West Midland Meres that bear SSSI status. Final Report to English Nature, Contract F72-06-14.

Moss, B., McGowan, S. & Carvalho, L (1994) Determination of phytoplankton crops by top-Down and bottom-up mechanisms in a group of English Lakes, the West Midland Meres. *Limnology and Oceanography*, **39**, 1020-1029.

Natural England (2008) Conservation objectives and definitions of favourable condition for designated features of interest: Tatton Meres.

Overpeck, J.T., Webb, T. & Prentice, I.C. (1985). Quantitative interpretation of fossil pollen spectra - dissimilarity coefficients and the method of modern analogs. *Quaternary Research,* **23**, 87-108.

Reynolds, C.S. & Sinker, C.A. (1976) The meres: Britain's eutrophic lakes. *New Scientist*, **71**, 10-12.

Rose N.L. (1994). A note on further refinements to a procedure for the extraction of carbonaceous fly-ash particles from sediments. *Journal of Paleolimnology,* **11**, 201-204.

Rose, N.L. (2008). Quality control in the analysis of lake sediments for spheroidal carbonaceous particles. *Limnology and Oceanography: Methods*, **6**, 172-179.

Rose, N.L. & Appleby, P.G. (2005) Regional applications of lake sediment dating by spheroidal carbonaceous particle analysis I: United Kingdom. *Journal of Paleolimnology,* **34**, 349-361.

Rose, N.L., Harlock, S., Appleby, P.G. & Battarbee, R.W. (1995) The dating of recent lake sediments in the United Kingdom and Ireland using spheroidal carbonaceous particle concentration profiles. *Holocene***, 5**, 328-335

Sayer, C. D., Burgess, A., Kari, K., *et al.* (2010). Long-term dynamics of submerged macrophytes and algae in a small and shallow, eutrophic lake: implications for the stability of macrophyte dominance. *Freshwater Biology*, **55**, 565–83.

Simpson, G.L (2005). *Defining restoration targets for acidified upland lakes using diatom and cladoceran sub-fossil remains and the modern analogue approach*. Unpublished Ph.D Thesis. University of London.

Simpson, G.L., Shilland, E. M., Winterbottom, J. M. & Keay, J. (2005). Defining reference conditions for acidified waters using a modern analogue approach. *Environmental Pollution*, **137,** 119-133.

ter Braak C. J. F. & Juggins, S. (1993) Weighted averaging partial least squares (WA-PLS): an improved method for reconstructing environmental variables from species assemblages. *Hydrobiologia,* **269/270**, 485-502.

ter Braak, C.J.F. & Prentice, I.C. (1988). A theory of Gradient Analysis. *Advances in Ecological Research*, **18**, 271-317.

ter Braak, C. J. F. & van Dam, H. (1989) Inferring pH from diatoms: a comparison of old and new calibration methods. *Hydrobiologia,* **178**, 209-223.

Vadeboncoeur, Y., Jeppesen, E., Vander Zanden, M.J., Schierup, H.H., Christoffersen K. & Lodge D.M. (2003). From Greenland to Green Lakes: cultural eutrophication and the loss of benthic pathways in lakes. *Limnology and Oceanography*, **48**, 1408-1418.

Willby, NJ, Pitt,JA & Phillips, G (2009) *The ecological classification of UK lakes using aquatic macrophytes*. Environment Agency Science Report - SC010080/SR. Environment Agency, Bristol.

Zhao, Y., Sayer, C., Birks, H., Hughes, M. & Peglar, S. (2006) Spatial representation of aquatic vegetation by macrofossils and pollen in a small and shallow Lake. *Journal of Paleolimnology,* **35**, 335-350.

APPENDIX 1 DIATOM DATA

Percentage data for Melchett Mere (MELC3)

% data						Depth (cm)			
Full Name	**Code**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**40**
Achnanthes conspicua	AC023A	**0.0**	**0.0**	**0.3**			**0.0**	**0.0**	**0.0**
Achnanthes exigua	AC008A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**
Achnanthidium minutissimum	AC013A	**2.2**	**1.4**	**1.0**			**25.8**	**21.6**	**19.2**
Adlafia bryophila	NA045A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**1.3**
Amphora pediculus	AM012A	**0.9**	**0.8**	**0.0**			**0.0**	**0.4**	**0.3**
Asterionella formosa	AS001A	**9.7**	**2.5**	**1.6**			**1.4**	**2.6**	**1.0**
Aulacoseira ambigua	AU002A	**36.7**	**44.2**	**34.0**			**1.8**	**9.5**	**12.5**
Aulacoseira granulata	AU003A	**25.1**	**10.4**	**5.8**			**2.9**	**1.3**	**1.3**
Cocconeis placentula var. euglypta	CO001B	**0.3**	**0.0**	**1.0**			**0.0**	**0.0**	**0.0**
Cyclostephanos dubius	CC001A	**0.3**	**2.8**	**0.0**			**1.4**	**0.9**	**0.0**
Cyclotella pseudostelligera	CY002A	**1.3**	**0.0**	**0.0**			**0.0**	**0.0**	**0.0**
Cyclotella radiosa	CY019A	**0.6**	**0.3**	**3.9**			**1.8**	**3.0**	**1.9**
Cymbella affinis	CM022A	**0.0**	**0.0**	**0.3**			**0.0**	**0.0**	**0.3**
Cymbella lanceolata	CM041A	**0.0**	**0.0**	**0.0**			**0.4**	**0.0**	**0.0**
Cymbella subaequalis	CM050A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**
Diatoma tenue	DT004A	**0.0**	**0.0**	**0.0**			**0.7**	**0.4**	**0.3**
Diploneis oblongella	DP007A	**0.0**	**0.0**	**0.0**			**2.2**	**1.3**	**1.6**
Diploneis spp	DP9999	**0.0**	**0.3**	**0.3**			**0.0**	**0.0**	**0.0**
Encyonema silesiacum	CM103A	**0.0**	**0.8**	**0.3**			**0.7**	**0.0**	**0.6**
Encyonopsis microcephala	CM004A	**0.0**	**0.3**	**0.0**			**0.0**	**0.0**	**0.0**
Eolimna minima	NA042A	**0.0**	**0.0**	**0.0**			**2.2**	**1.7**	**2.2**
Eunotia curvata	EU049A	**0.0**	**0.0**	**0.0**			**6.1**	**4.8**	**8.0**
Eunotia minor	EU002B	**0.0**	**0.0**	**0.3**			**2.5**	**2.2**	**4.8**
Fallacia lucinensis	NA748A	**0.3**	**0.3**	**0.0**			**0.0**	**0.0**	**0.0**
Fallacia tenera	NA676A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**
Fragilaria capucina	FR009A	**0.0**	**1.4**	**0.3**			**0.0**	**0.0**	**0.0**
Fragilaria capucina var. gracilis	FR009H	**0.0**	**0.6**	**0.3**			**0.0**	**0.0**	**0.0**
Fragilaria famelica	SY043A	**0.0**	**0.0**	**0.0**			**7.2**	**5.2**	**2.2**
Fragilaria tenera	FR060A	**0.0**	**0.0**	**0.0**			**2.9**	**6.1**	**2.9**
Fragilaria vaucheriae	FR007A	**0.0**	**0.0**	**0.0**			**0.7**	**0.4**	**0.0**
Fragilariforma bicapitata	FR003A	**0.0**	**0.0**	**0.3**			**0.0**	**0.0**	**0.0**
Geissleria decussis	NA317A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**

Gomphoneis olivaceum	GM001A	**0.0**	**0.0**	**0.0**			**0.4**	**0.0**	**0.0**
Gomphonema angustatum	GO003A	**0.0**	**0.0**	**0.0**			**2.2**	**1.3**	**0.6**
Gomphonema angustum	GO073A	**0.3**	**0.3**	**0.3**			**0.0**	**0.4**	**1.6**
Gomphonema parvulum	GO013A	**0.0**	**0.0**	**0.0**			**1.8**	**2.2**	**4.5**
Gomphonema truncatum	GO023A	**0.0**	**0.0**	**0.0**			**0.7**	**0.0**	**0.0**
Gyrosigma acuminatum	GY005A	**0.0**	**0.0**	**0.3**			**0.4**	**0.0**	**0.0**
Hippodonta capitata	NA066A	**0.3**	**0.3**	**0.0**			**0.4**	**0.4**	**0.0**
Hippodonta costulata	NA299A	**0.0**	**0.0**	**0.3**			**0.0**	**0.0**	**0.0**
Karayevia clevei	AC006A	**0.0**	**0.3**	**0.3**			**0.0**	**0.0**	**0.6**
Meridion circulare	MR001A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**
Navicula cari	NA051A	**0.0**	**0.0**	**0.3**			**0.0**	**0.0**	**0.0**
Navicula cryptocephala	NA007A	**0.3**	**0.3**	**0.0**			**0.4**	**2.6**	**0.6**
Navicula gregaria	NA023A	**0.0**	**0.0**	**0.0**			**0.7**	**1.3**	**0.3**
Navicula lanceolata	NA009A	**0.0**	**0.3**	**0.0**			**0.0**	**0.0**	**0.0**
Navicula menisculus	NA030A	**0.3**	**0.0**	**0.0**			**0.0**	**1.3**	**0.3**
Navicula praeterita	NA578A	**0.3**	**0.3**	**0.0**			**0.4**	**0.0**	**0.0**
Navicula pseuodtuscula	NA589A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**
Navicula radiosa	NA003A	**1.6**	**1.4**	**1.0**			**1.4**	**2.6**	**1.3**
Navicula reichardtiana	NA768A	**0.0**	**0.3**	**0.3**			**0.4**	**0.4**	**0.3**
Navicula reinhardtii	NA026A	**0.0**	**0.0**	**0.6**			**0.4**	**0.0**	**0.0**
Navicula rhyncocephala	NA008A	**0.0**	**0.0**	**0.0**			**0.4**	**0.0**	**0.0**
Navicula tripuntata	NA095A	**0.0**	**0.3**	**0.0**			**0.0**	**0.0**	**0.0**
Navicula veneta	NA054A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.3**
Navicula viridula	NA027A	**0.0**	**0.3**	**0.0**			**0.0**	**0.0**	**0.0**
Nitzschia amphibia	NI014B	**0.0**	**0.0**	**0.6**			**0.0**	**0.9**	**0.0**
Nitzschia linearis	NI031A	**0.0**	**0.0**	**0.0**			**0.4**	**0.0**	**0.0**
Nitzschia palea	NI009A	**0.0**	**0.0**	**0.0**			**0.0**	**0.4**	**0.3**
Nitzschia perminuta	NI193A	**0.0**	**0.0**	**0.0**			**2.5**	**1.7**	**1.0**
Nitzschia recta	NI025A	**0.0**	**0.0**	**0.0**			**0.4**	**0.0**	**0.3**
Nitzschia tubicola	NI048A	**0.0**	**0.0**	**0.0**			**0.0**	**0.4**	**0.3**
Opephora oldenburgiana	FR013A	**0.0**	**0.6**	**1.0**			**0.0**	**0.0**	**0.0**
Pinnularia subcapitata	PI022A	**0.0**	**0.0**	**0.0**			**0.4**	**0.9**	**1.6**
Placoneis clementis	NA050A	**0.3**	**0.3**	**0.3**			**0.0**	**0.0**	**0.0**
Planothidium granum	AC158A	**0.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.6**
Planothidium lanceolatum	AC001A	**1.3**	**0.0**	**0.6**			**6.1**	**6.1**	**4.8**
Pseudostaurosira brevistriata	FR006A	**2.5**	**4.5**	**6.5**			**0.4**	**0.4**	**1.3**
Sellaphora pupula	NA014A	**0.3**	**0.3**	**0.3**			**0.0**	**1.7**	**0.6**

Sellaphora seminulum	NA005A	**0.0**	**0.0**	**0.0**			**4.7**	**2.2**	**7.7**
Stauroneis anceps	SA001A	**0.0**	**0.0**	**0.0**			**0.4**	**0.4**	**0.0**
Stauroneis smithii	SA003A	**0.0**	**0.0**	**0.0**			**0.0**	**1.3**	**0.0**
Staurosira construens	FR002A	**0.3**	**3.7**	**2.9**			**0.7**	**0.4**	**0.6**
Staurosira construens var. venter	FR002C	**4.4**	**7.3**	**15.2**			**3.6**	**1.7**	**2.2**
Staurosira elliptica	FR018A	**0.0**	**0.6**	**1.6**			**0.0**	**0.0**	**0.0**
Staurosirella pinnata	FR001A	**6.6**	**5.1**	**11.7**			**0.4**	**1.7**	**2.2**
Stephanodiscus hantzschii	ST001A	**0.6**	**0.8**	**0.3**			**1.1**	**1.3**	**0.6**
Stephanodiscus neoastraea	ST022A	**0.3**	**0.3**	**0.0**			**0.0**	**0.0**	**0.0**
Stephanodiscus parvus	ST010A	**2.2**	**5.9**	**5.5**			**6.1**	**2.2**	**1.0**
Synedra acus var. angustissima	SY003C	**0.0**	**0.3**	**0.0**			**0.7**	**0.9**	**0.6**
Synedra parasitica	FR045A	**0.3**	**0.0**	**0.0**			**0.0**	**0.0**	**0.0**
Synedra ulna	SY001A	**0.3**	**0.3**	**0.3**			**1.4**	**0.9**	**1.0**
Tabellaria flocculosa	TA001A	**0.0**	**0.0**	**0.0**			**0.7**	**0.4**	**0.3**

Slides 15-16 & 20-21 cm: poor preservation and few diatoms.
Slide 35-36 cm: just poor slide - looked very similar to 30-31 cm, but not possible to count.
Slide 45-46 cm: Totally different particle structure (Soil, rather than silt?). Very few diatoms, and those present mainly aerophyllous *Pinnularia* species, suggesting wetland phase rather than lake sediments.

Percentage data for Tatton Mere (SCM41E)

% data									Depth (cm)			
Full Name	**Code**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**110**
Planothidium lanceolatum	AC001A	0.0	0.0	0.3	0.0	0.3	0.5	0.7	0.3	0.9	1.1	1.6
Karayevia clevei	AC006A	0.6	0.0	0.7	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Achnanthidium minutissimum	AC013A	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.3
Planothidium delicatulum	AC016A	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.3	0.3	0.0
Planothidium granum	AC158A	0.0	0.0	0.3	0.0	0.0	0.3	0.2	0.9	0.0	0.0	1.1
Amphora libyca	AM011A	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Amphora pediculus	AM012A	1.0	0.5	1.0	0.3	0.0	0.0	0.5	0.6	0.3	1.4	0.3
Amphora inariensis	AM013A	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Asterionella formosa	AS001A	7.8	1.6	5.2	4.3	1.9	0.8	0.2	0.0	0.0	1.1	0.0
Asterionella ralfsii	AS003A	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aulacoseira ambigua	AU002A	23.7	9.6	2.6	0.6	0.0	0.0	0.5	0.3	0.3	0.6	0.3
Aulacoseira granulata	AU003A	9.1	1.1	3.9	4.0	3.1	1.0	0.2	1.2	0.3	0.3	0.0
Aulacoseira granulata var. angustissima	AU003B	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caloneis bacillum	CA002A	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyclostephanos dubius	CC001A	0.0	0.0	1.0	10.2	21.7	2.6	0.0	3.2	0.3	1.1	0.8
Cyclostephanos cf. tholiformis	CC9997	1.6	0.8	1.3	0.3	1.9	0.0	0.0	0.0	0.0	0.3	1.3
Encyonema silesiacum	CM103A	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Cocconeis placentula var. placentula	CO001A	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Cocconeis placentula var. euglypta	CO001B	0.0	0.8	0.3	0.3	1.2	0.0	0.2	0.3	0.3	0.3	0.3
Cocconeis pediculus	CO005A	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.3	0.0	0.3	0.0
Cocconeis neothumensis	CO067A	0.0	0.5	0.0	0.6	0.3	0.0	0.5	0.0	0.9	0.0	0.0
Cyclotella pseudostelligera	CY002A	1.3	2.5	1.6	0.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Cyclotella meneghiniana	CY003A	0.3	0.0	0.0	0.0	0.3	0.3	0.2	0.3	0.3	0.3	0.3
Cyclotella radiosa	CY019A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
Diploneis spp	DP9999	0.0	0.0	0.3	0.0	0.9	0.0	0.0	0.0	0.0	0.3	0.3
Diatoma tenue	DT004A	0.0	0.3	1.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3
Epithemia sp.	EP9999	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosirella pinnata	FR001A	2.9	1.4	2.3	2.8	2.2	1.3	1.4	1.2	0.3	0.9	1.3
Staurosira construens	FR002A	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.1	1.2	1.4	0.5
Staurosira binodis	FR002B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.0	0.8
Staurosira construens var. venter	FR002C	2.9	0.5	0.7	1.2	1.5	0.0	0.5	0.0	0.0	1.4	2.4
Staurosira construens var. subsalina	FR002E	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudostaurosira brevistriata	FR006A	1.9	0.0	1.3	0.9	0.0	2.1	1.0	3.5	0.0	0.6	2.4
Fragilaria vaucheriae	FR007A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Fragilaria crotonensis	FR008A	0.0	0.3	0.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fragilaria capucina	FR009A	0.6	0.3	0.7	1.6	2.2	1.3	0.5	1.8	0.3	1.1	1.6
Fragilaria capucina var. mesolepta	FR009B	0.0	0.0	0.0	0.9	0.0	1.0	0.0	0.6	0.3	0.3	0.0
Opephora oldenburgiana	FR013A	1.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0

Staurosira elliptica	FR018A	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.5	0.0	0.3	0.5
Fragilaria bidens	FR026A	0.0	0.3	0.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra parasitica	FR045A	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra parasitica var. subconstricta	FR045E	0.0	0.0	0.0	0.6	0.3	0.3	0.0	0.3	0.0	0.0	0.0
Gomphoneis olivaceum	GM001A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomphonema parvulum	GO013A	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3
Gomphonema truncatum	GO023A	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomphonema minutum	GO050A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Gomphonema angustum	GO073A	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hippodonta hungarica	NA004A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Sellaphora pupula	NA014A	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0
Navicula gregaria	NA023A	0.0	0.5	0.0	0.0	0.3	0.3	0.2	0.9	0.0	1.1	0.3
Luticola mutica	NA025A	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Navicula reinhardtii	NA026A	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cavinula scutelloides	NA028A	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6	0.6	1.3
Navicula menisculus	NA030A	0.6	0.3	0.0	0.0	0.3	0.0	0.2	0.9	0.0	0.0	0.0
Eolimna minima	NA042A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Placoneis clementis	NA050A	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.3
Navicula cari	NA051A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Hippodonta capitata	NA066A	0.3	0.3	0.0	0.0	0.0	0.0	0.5	0.6	0.3	0.0	0.3
Navicula tripuntata	NA095A	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Sellaphora vitabunda	NA168A	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Geissleria decussis	NA317A	0.0	0.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geissleria ignota var . acceptata	NA433B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.9	0.0
Navicula praeterita	NA578A	0.0	0.0	1.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Navicula capitoradiata	NA745A	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Navicula cryptotenella	NA751A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula reichardtiana	NA768A	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Nitzschia fonticola	NI002A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Nitzschia palea	NI009A	0.0	0.0	0.7	0.3	0.3	0.3	0.7	0.0	0.3	0.0	0.0
Nitzschia amphibia	NI014B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Nitzschia dissipata	NI015A	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia recta	NI025A	0.3	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhoicosphenia abbreviata	RC002A	0.3	0.5	0.3	0.6	0.9	0.3	0.0	0.3	0.0	0.6	0.5
Stephanodiscus hantzschii	ST001A	5.5	19.4	8.2	7.1	9.3	7.2	3.9	4.7	4.6	3.7	2.7
Stephanodiscus parvus	ST010A	32.5	56.0	58.8	57.5	43.3	78.8	86.3	70.2	86.5	71.4	37.8
Stephanodiscus medius	ST014A	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0
Stephanodiscus neoastraea	ST022A	0.6	0.5	0.3	0.3	1.2	0.0	0.5	1.8	0.0	7.1	37.2
Surirella brebisonii	SU073A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra ulna	SY001A	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Synedra acus	SY003A	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Tabularia fasciculata	SY005A	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0

Percentage data for Comber Mere (SCM14B)

% data					Depth (cm)						
Full Name	**Code**	**0**	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**70**
Planothidium lanceolatum	AC001A	0.0	0.9	1.6	0.9	1.3	0.6	1.3	2.2	4.4	3.8
Karayevia clevei	AC006A	0.3	1.2	0.7	1.6	2.0	1.5	0.6	1.2	0.9	0.9
Achnanthes exigua	AC008A	0.0	0.9	0.0	1.6	1.6	4.7	3.9	2.8	1.9	2.3
Achnanthidium minutissimum	AC013A	0.0	0.0	0.3	0.3	0.0	0.9	0.0	0.6	0.0	0.3
Planothidium delicatulum	AC016A	0.0	0.0	0.7	0.0	0.7	0.3	0.0	0.0	0.3	0.0
Achnanthes conspicua	AC023A	0.0	0.0	0.0	0.3	0.3	0.6	0.6	0.0	0.3	0.0
Planothidium granum	AC158A	0.0	0.3	0.3	0.9	0.7	0.6	0.6	3.4	3.8	2.6
Amphora libyca	AM011A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Amphora pediculus	AM012A	1.3	1.2	2.0	5.3	1.6	3.2	3.9	5.2	3.8	4.7
Asterionella formosa	AS001A	4.9	1.5	13.0	7.8	14.4	6.5	1.3	2.2	8.5	2.6
Aulacoseira granulata	AU003A	13.8	13.5	14.7	6.6	1.6	1.8	1.0	0.0	0.3	0.6
Cyclostephanos dubius	CC001A	2.0	0.3	0.0	3.8	10.8	10.0	4.5	2.5	5.4	1.5
Cyclostephanos cf. tholiformis	CC9997	1.0	0.0	0.7	0.6	1.6	0.6	0.3	0.0	0.0	0.0
Cocconeis placentula var. placentula	CO001A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Cocconeis placentula var. euglypta	CO001B	0.0	0.3	0.3	0.0	0.7	0.3	0.3	0.3	0.6	0.3
Cocconeis pediculus	CO005A	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Cocconeis neothumensis	CO067A	0.0	0.0	1.0	1.6	1.6	0.0	1.3	0.3	1.9	1.8
Cyclotella pseudostelligera	CY002A	0.0	0.0	0.7	0.3	0.0	0.3	0.0	0.0	0.3	0.0
Cyclotella meneghiniana	CY003A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Cyclotella ocellata	CY009A	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.3
Cyclotella radiosa	CY019A	0.0	0.0	0.0	0.0	0.0	0.0	13.2	14.8	8.5	10.0
Cyclotella aff. comensis	CY9991	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diatoma vulgare	DT003A	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diatoma tenue	DT004A	0.0	0.0	0.3	0.6	0.3	0.0	0.0	0.0	0.0	0.0
Epithemia sp.	EP9999	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.6	0.0
Staurosirella pinnata	FR001A	3.6	3.4	0.3	2.2	1.3	2.9	3.9	2.8	4.1	7.3
Staurosira construens	FR002A	0.3	1.2	0.0	0.3	1.6	0.3	1.6	1.2	3.2	4.1
Staurosira binodis	FR002B	0.0	0.3	0.3	0.0	0.0	0.3	0.6	1.2	0.9	1.2
Staurosira construens var. venter	FR002C	3.3	5.5	2.0	0.9	1.6	3.8	3.2	2.8	5.7	3.8
Pseudostaurosira brevistriata	FR006A	9.8	11.7	1.3	3.1	2.3	7.6	5.1	4.9	3.8	5.3
Fragilaria vaucheriae	FR007A	0.0	0.6	0.0	0.0	0.0	0.9	1.3	0.3	0.9	0.0
Fragilaria crotonensis	FR008A	0.0	0.0	2.0	0.3	0.3	0.0	0.0	0.3	0.0	0.0
Fragilaria capucina	FR009A	0.0	1.8	0.3	0.3	1.0	1.2	1.3	1.2	1.6	0.6
Fragilaria capucina var. mesolepta	FR009B	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3
Opephora oldenburgiana	FR013A	0.0	0.0	0.3	0.0	1.0	0.3	0.6	0.6	0.9	0.6
Staurosirella lapponica	FR014A	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosira elliptica	FR018A	1.6	2.8	1.0	0.0	2.6	0.3	0.3	1.2	0.0	0.0
Synedra parasitica var. subconstricta	FR045E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0

Gomphoneis olivaceum	GM001A	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Gomphonema parvulum	GO013A	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomphonema clevei	GO024A	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.3
Gomphonema minutum	GO050A	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Gyrosima acuminatum	GY005A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Melosira vaians	ME015A	0.0	0.3	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Sellaphora seminulum	NA005A	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0
Sellaphora pupula	NA014A	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	1.6	0.9
Navicula gregaria	NA023A	0.7	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0
Cavinula scutelloides	NA028A	0.0	0.0	0.0	0.3	0.3	0.3	1.9	0.6	0.3	0.3
Navicula menisculus	NA030A	0.3	0.9	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Eolimna minima	NA042A	0.3	0.0	0.0	0.3	1.0	0.3	0.0	0.3	0.3	0.9
Placoneis clementis	NA050A	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Navicula cari	NA051A	0.0	0.6	0.3	0.6	1.0	0.9	0.6	0.3	0.0	0.9
Hippodonta capitata	NA066A	0.3	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
Navicula tripuntata	NA095A	0.0	0.0	0.3	0.3	0.0	0.6	0.0	0.0	0.6	0.3
Navicula subrotundata	NA114A	0.3	0.3	0.7	0.3	1.0	2.1	9.0	6.5	5.4	3.5
Eolimna subminuscula	NA134A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Sellaphora vitabunda	NA168A	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6
Geissleria decussis	NA317A	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.6	0.3	0.0
Geissleria ignota var . acceptata	NA433B	0.3	0.0	0.3	0.9	0.3	0.0	0.6	1.2	0.0	0.3
Navicula praeterita	NA578A	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula capitoradiata	NA745A	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Fallacia lucinensis	NA748A	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Navicula cryptotenella	NA751A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Navicula reichardtiana	NA768A	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.3
Nitzschia fonticola	NI002A	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Nitzschia palea	NI009A	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Nitzschia amphibia	NI014B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Nitzschia dissipata	NI015A	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6	0.3
Rhoicosphenia abbreviata	RC002A	0.3	0.0	0.3	0.3	1.0	1.2	0.3	0.0	0.3	0.0
Stephanodiscus hantzschii	ST001A	18.0	8.0	11.1	5.0	4.6	5.9	8.0	1.9	1.6	0.9
Stephanodiscus parvus	ST010A	29.5	36.0	42.3	50.0	36.1	35.2	10.3	22.2	21.2	33.4
Stephanodiscus medius	ST014A	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stephanodiscus neoastraea	ST022A	2.3	3.4	0.3	0.3	0.7	1.8	16.4	11.4	1.9	0.6
Synedra ulna	SY001A	0.3	0.3	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.3
Synedra ulna var. acus	SY003A	1.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tabularia fasciculata	SY005A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3

APPENDIX 2 MACROFOSSIL DATA
(Zooplankton ephippia data are highlighted in green)

Melchett Mere (MELC3)

Numbers per 100cm3					Depth (cm)						
Full name	**Code**	**0**	**8**	**15**	**18**	**21**	**25**	**28**	**35**	**38**	**45**
Gloeotrichia	AlBallsLI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	0.00
Betula bract (female catkin)	BetPCat	0.00	0.00	0.00	0.00	0.00	3.33	0.00	3.33	0.00	0.00
Betula seeds	BetSe	0.00	0.00	6.67	3.33	0.00	3.33	10.00	16.67	26.67	3.33
Callitriche seed	CallSee	3.33	0.00	0.00	3.33	0.00	0.00	6.67	0.00	3.33	0.00
Carex subgenus vignea seed	CaVigSee	0.00	0.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00	3.33
Cerastium seed	CeraSee	0.00	0.00	0.00	0.00	3.33	0.00	0.00	3.33	10.00	0.00
Fern sporangium	Fern125	16.67	33.33	0.00	0.00	83.33	33.33	66.67	33.33	16.67	0.00
Epilobium hirsutum seed	EpHiSee	0.00	0.00	0.00	0.00	3.33	0.00	0.00	3.33	0.00	0.00
Epilobium palustre	EpPaSee	0.00	0.00	0.00	0.00	0.00	0.00	3.33	0.00	0.00	0.00
Glyceria seed	GlySee	0.00	3.33	0.00	0.00	0.00	23.33	6.67	6.67	26.67	0.00
Juncus spp seeds	JuncSee	483.33	333.33	566.67	886.67	3130.00	4196.67	1390.00	4963.33	6590.00	3640.00
Lychnis flos- cuculi seed	LyFlSee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	20.00	0.00
Moss golden	MossG	53.33	23.33	36.67	80.00	170.00	70.00	136.67	20.00	40.00	6.67
Sphagnum moss	MossSg	3.33	13.33	3.33	3.33	3.33	6.67	13.33	0.00	0.00	3.33
Nymphaea alba seed fragments	NyAlFr	0.00	0.00	0.00	0.00	10.00	3.33	0.00	0.00	0.00	0.00
Oospores of Chara (oval)	OOScO125	0.00	0.00	0.00	0.00	0.00	0.00	8.33	0.00	0.00	83.33
Potamegeton berchtoldii/ pusillis leaf tips	PotBercTips	33.33	0.00	6.67	13.33	10.00	6.67	0.00	0.00	0.00	3.33
Potamogeton fine leaf fragments	PotFineFr	16.67	23.33	20.00	23.33	46.67	10.00	26.67	16.67	20.00	0.00
Potamogeton unident seed (decayed)	PotSeeUn	0.00	0.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00	0.00
Ranunculus seed	Ran2See	0.00	0.00	3.33	0.00	3.33	26.67	6.67	0.00	6.67	0.00
Ceriodaphnia spp.	Cerio125	66.67	50.00	16.67	33.33	0.00	8.33	0.00	16.67	0.00	0.00
Daphnia hyalina agg.	DaHy	156.67	226.67	185.00	93.33	33.33	43.33	25.00	70.00	35.00	10.00
Daphnia pulex	DaPu350	11.67	6.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Simocephalus spp.	Sim350	0.00	0.00	10.00	6.67	0.00	11.67	8.33	0.00	10.00	0.00

Tatton Mere (SCM41F)

Numbers per 100cm3						Depth (cm)					
Full name	**Code**	**2**	**10**	**20**	**25**	**30**	**40**	**45**	**50**	**60**	**70**
Gloeotrichia	AlBallsLl	12.00	4.00	12.00	20.00	26.67	33.33	23.33	76.00	3.33	20.00
Betula bract	BetBrac	0.00	0.00	0.00	0.00	0.00	0.00	20.00	4.00	3.33	3.33
Betula seeds	BetSe	12.00	0.00	8.00	28.00	6.67	6.67	56.67	24.00	50.00	326.67
Callitriche seed	CallSee	16.00	22.00	2.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00
Carex subgenus vignea seed	CaVigSee	0.00	0.00	4.00	4.00	10.00	10.00	13.33	28.00	10.00	16.67
Carex spp seed (triangular)	CaTrSee	0.00	0.00	4.00	0.00	0.00	0.00	0.00	8.00	0.00	0.00
Glyceria seed	GlySee	0.00	12.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fern sporangium	Fern125	180.00	120.00	0.00	280.00	216.67	166.67	233.33	160.00	1100.00	3183.33
Juncus spp seeds	JuncSee	1928.00	1768.00	3184.00	2556.00	2440.00	1583.33	700.00	420.00	116.67	203.33
Menyanthes trifoliata seed	MenTrSe	0.00	0.00	0.00	0.00	0.00	0.00	5.00	10.00	0.00	5.00
Moss golden	MossG	52.00	0.00	404.00	368.00	1516.67	786.67	1206.67	660.00	20.00	123.33
Nymphea alba seed	NyAlSee	0.00	0.00	0.00	0.00	0.00	0.00	6.67	8.00	6.67	3.33
Sphagnum moss	MossSg	24.00	56.00	972.00	1236.00	1356.67	1206.67	463.33	492.00	283.33	166.67
Nymphaea alba seed fragments	NyAlFr	0.00	4.00	8.00	20.00	23.33	26.67	23.33	84.00	0.00	16.67
Oospores of Chara (long)	OOScL	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oospores of Chara Hairy (oval)	OOScHO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	0.00
Oospores of Chara (oval)	OOScO	172.00	32.00	8.00	38.00	0.00	0.00	31.67	44.00	63.33	285.00
Nymphaeaceae trychosclereids	NyTry125	0.00	0.00	80.00	80.00	66.67	116.67	150.00	140.00	16.67	83.33
Oospores Nitella (hairy) spp.	OOSHn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.00	0.00	0.00
Oospores Nitella spp.	OOSn	0.00	0.00	8.00	0.00	0.00	3.33	10.00	0.00	0.00	0.00
Oospores Nitella (small, orange) spp. (125 Fraction)	OOSnSm125	0.00	0.00	0.00	20.00	0.00	0.00	75.00	250.00	0.00	0.00
Lemna leaves	LemnaSppL	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potamogeton berchtoldii/ pusillis leaf tips	PotBercTips	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potamogeton obtusifolius leaf tips	PotObTips	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potamogeton unident leaf tips	PotUnTips	0.00	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potamogeton fine leaf fragments	PotFineFr	8.00	8.00	8.00	4.00	0.00	3.33	0.00	4.00	0.00	6.67
Potamogeton obtusifolius seeds	PotObSee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	3.33
Potamogeton cf natans seed	PotNatSee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33
Potamogeton pusillis seed	PotPuSee	0.00	0.00	4.00	0.00	0.00	0.00	6.67	4.00	0.00	0.00
Potamogeton unident seed (decayed)	PotSeeUn	0.00	0.00	8.00	4.00	0.00	3.33	3.33	4.00	0.00	0.00
Myriophyllum seeds	MySee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00
Potentilla spp seed	PotenSee	4.00	0.00	0.00	0.00	0.00	0.00	0.00	12.00	0.00	0.00
Ranunculus subgenus Batrachium seed fragments	RanSee	0.00	0.00	0.00	0.00	1.67	1.67	6.67	8.00	5.00	8.33
Rubus seed	RubSee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Typha latifolia seed	TyLaSee	0.00	0.00	0.00	28.00	3.33	3.33	0.00	0.00	0.00	0.00
Sagina spp seed (125 fraction)	SagSee125	0.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00

Zannichellia palustris seeds	ZanSee	4.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unident seed	UnidentS	0.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ceriodaphnia spp.	Cerio	20.00	0.00	0.00	0.00	1.67	50.00	16.67	0.00	0.00	16.67
Daphnia hyalina agg.	DaHy	806.00	668.00	158.00	34.00	11.67	3.33	0.00	0.00	3.33	0.00
Daphnia pulex	DaPu	354.00	170.00	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daphnia magna	DaMa	12.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Simocephalus spp.	Sim	12.00	0.00	10.00	0.00	6.67	26.67	0.00	0.00	0.00	0.00

Comber Mere (SCM14C)

Numbers per 100cm3						**Depth (cm)**					
Full name	**Code**	**2**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**90**	**100**
Alisma plantago-aquatica seed	AlPlsee	0.00	0.00	6.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gloeotrichia	AlBallsLI	0.00	3.33	40.00	24.00	16.00	28.00	43.33	184.00	10.00	10.00
Betula bract (female catkin)	BetPCat	0.00	16.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Betula seeds	BetSe	10.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carex subgenus vignea seed	CaVigSee	5.00	6.67	6.67	8.00	0.00	0.00	3.33	0.00	0.00	0.00
Juncus spp seeds	JuncSee	0.00	0.00	66.67	80.00	20.00	24.00	0.00	20.00	50.00	100.00
Fern sporangium	Fern	325.00	83.33	600.00	340.00	460.00	100.00	366.67	1420.00	550.00	1016.67
Moss spikey leaves	MossSpik	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moss golden	MossG	95.00	0.00	36.67	68.00	324.00	320.00	10.00	32.00	33.33	106.67
Moss brown	MossBr	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sphagnum moss	MossSg	0.00	0.00	6.67	8.00	0.00	0.00	3.33	4.00	3.33	13.33
Nymphaea alba seed fragments	NyAlFr	10.00	0.00	76.67	176.00	88.00	208.00	83.33	104.00	66.67	30.00
Nymphaeaceae trichosclereids	NyTry	130.00	0.00	100.00	60.00	284.00	120.00	150.00	200.00	233.33	833.33
Oospores of Chara (oval)	OOScO	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	25.00	4.17
Oospores Nitella spp.	OOSn	0.00	0.00	6.67	20.00	0.00	0.00	0.00	0.00	0.00	0.00
Potamegeton c.f natans seed	PotNatSee	5.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potamegeton unident seed (decayed)	PotSeeUn	15.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Potamegeton seed fragments	PotSeeFr	0.00	6.67	13.33	8.00	0.00	0.00	0.00	0.00	0.00	0.00
Ranunculus subgenus Batrachium seed fragments	RanSee	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Typha latifolia seed	TyLaSee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33
Unident four sided seed	UnFour	0.00	16.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ceriodaphnia spp.	Cerio	45.00	110.00	526.67	32.00	24.00	0.00	0.00	0.00	0.00	0.00
Daphnia hyalina agg.	DaHy	305.00	180.00	0.00	32.00	0.00	0.00	8.33	34.00	18.33	38.33
Daphnia pulex	DaPu	65.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33
Daphnia magna	DaMa	50.00	6.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 3 CLADOCERA DATA

Melchett Mere (MELC3)

% data					Depth (cm)			
Full name	**code**	**0**	**10**	**15**	**20**	**30**	**40**	**48**
	Total	453.27	417.50	790.18	900.07	850.51	498.39	367.06
Acroperus harpae	CACHA	1.99	0.06	0.86	0.36	0.15	0.49	0.51
Alona affinis	CALAF	0.97	0.09	0.06	1.06	0.06	0.12	0.09
Alona costata	CALCO	0.10	1.30	0.44	0.21	0.10	0.09	0.09
Alona guttata/rectangula	CALGR	3.53	3.46	0.98	1.78	3.15	1.26	0.30
Alona intermedia	CALIN	0.86	0.00	0.13	0.00	0.00	0.00	0.00
Alona quadrangularis	CALQU	2.87	5.47	6.49	1.96	3.23	7.06	2.19
Bosmina coregoni	CBOCO	5.37	3.80	25.93	25.98	4.76	0.00	0.00
Bosmina longirostris	CBOLO	70.94	78.82	56.14	61.76	70.38	84.79	91.77
Chydorus sphaericus	CCHSP	5.49	3.43	4.00	5.54	15.96	5.99	4.89
Daphnia longispina/hyalina	CDALH	5.18	1.15	1.59	0.00	1.05	0.00	0.00
Eurycercus lamellatus	CEULA	2.62	1.15	2.52	0.67	0.06	0.12	0.09
Graptolebris testudinaria	CGRTE	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Leydigia leydigii	CLELI	0.03	1.18	0.00	0.60	1.05	0.03	0.04
Pleuroxus uncinatus	CPLUN	0.00	0.03	0.86	0.07	0.06	0.06	0.04
Cyclops	CYCL	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Tatton Mere (SCM14E)

% data							Depth (cm)						
Full name	**code**	**0**	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**100**
	Total	297.11	377.36	1059.14	427.85	533.89	796.18	511.79	404.20	1921.52	1928.20	1934.73	1214.94
Acroperus harpae	CACHA	1.21	2.02	1.86	1.28	1.03	1.44	2.59	0.26	0.00	0.06	0.34	0.38
Alona affinis	CALAF	3.02	4.37	3.37	1.58	1.61	1.43	2.04	7.15	0.68	1.45	0.80	0.54
Alona costata	CALCO	2.42	1.46	2.04	1.50	1.61	0.29	0.55	0.64	0.36	0.66	0.69	0.40
Alona guttata/rectangula	CALGR	4.13	1.46	0.71	0.13	0.49	1.20	0.27	0.26	0.27	0.48	0.68	0.76
Alona guttata var tuberculata	CALGT	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
Alona intermedia	CALIN	0.00	0.21	0.18	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alonella nana	CALNA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.68	0.38
Alona quadrangularis	CALQU	7.27	13.11	11.08	8.06	8.08	7.77	5.40	5.57	4.17	5.53	6.06	4.00
Alona rectangula	CALRE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00
Alona rustica	CALRU	0.00	0.00	0.45	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alonella excisa	CALXS	0.00	1.46	0.71	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bosmina coregoni	CBOCO	14.67	1.75	13.04	12.30	27.91	6.71	1.54	50.39	60.42	67.00	64.63	56.67
Bosmina longirostris	CBOLO	50.05	51.25	52.58	56.35	50.49	59.82	70.11	14.48	24.70	6.29	7.51	4.58
Camptocercus rectirostris	CCARE	0.20	0.07	0.35	0.00	0.00	0.00	0.18	0.26	0.15	0.45	0.11	0.71
Chydorus sphaericus	CCHSP	4.33	11.85	10.09	9.20	4.78	18.62	9.93	16.11	7.82	11.98	14.39	25.13
Daphnia longispina/hyalina	CDALH	3.63	1.46	0.18	1.28	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurycercus lamellatus	CEULA	1.41	3.13	0.53	0.18	1.20	1.26	0.40	0.00	0.00	0.00	0.00	0.00
Graptolebris testudinaria	CGRTE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00
Leydigia leydigii	CLELI	0.51	0.35	0.71	0.00	0.16	0.11	1.40	0.13	0.27	0.09	0.11	0.93
Monospilus dispar	CMODI	1.21	0.92	0.89	1.28	0.25	0.00	2.88	1.63	0.00	2.70	1.60	3.20
Phiruxa rostrata	CPHIR	0.30	0.14	0.35	0.00	0.00	0.00	0.18	0.00	0.00	0.18	0.57	0.62
Pleuroxus denticulatus	CPLDE	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pleuroxus laevis	CPLLA	0.10	0.00	0.35	5.29	0.16	0.17	0.00	1.89	0.20	1.02	0.80	0.54
Pleuroxus uncinatus	CPLUN	5.44	3.41	0.53	1.37	1.20	1.20	2.52	1.24	0.64	1.15	0.80	0.76
Sida crystalina	CSICR	0.00	1.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Comber Mere (SCM14B)

% data							Depth (cm)						
Full name	**code**	**0**	**5**	**10**	**15**	**20**	**30**	**40**	**60**	**70**	**80**	**90**	**100**
	Total	315.69	675.65	1391.17	1689.99	1972.36	2216.04	1276.81	3032.36	1252.17	1238.31	1234.42	1580.59
Acroperus harpae	CACHA	3.14	1.63	1.10	0.27	1.22	0.93	1.43	2.04	2.88	3.30	1.17	1.79
Alona affinis	CALAF	0.41	0.88	0.48	0.47	0.13	0.45	0.00	0.75	0.11	0.71	0.48	0.06
Alona costata	CALCO	3.10	0.60	1.66	0.47	1.46	0.65	2.08	2.39	1.64	0.54	2.78	1.31
Alona guttata/rectangula	CALGR	0.37	1.13	1.03	0.47	1.33	0.93	0.88	1.29	0.54	1.41	0.90	1.33
Alona guttata var tuberculata	CALGT	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alona intermedia	CALIN	1.33	0.00	0.00	0.09	0.07	0.04	0.00	0.00	0.00	0.71	0.90	0.37
Alonella nana	CALNA	0.00	3.11	1.12	2.37	0.07	2.19	3.83	1.50	3.23	0.00	3.14	1.47
Alona quadrangularis	CALQU	9.83	4.02	4.16	5.41	7.59	4.70	14.08	5.58	9.10	9.27	6.52	5.20
Alonella excisa	CALXS	0.20	0.10	0.39	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bosmina coregoni	CBOCO	0.00	0.00	8.47	9.83	7.65	5.69	17.68	11.07	12.72	13.68	4.59	13.14
Bosmina longirostris	CBOLO	61.22	58.94	67.07	61.16	64.55	72.67	50.86	62.09	48.66	52.34	60.08	56.71
Camptocercus rectirostris	CCARE	0.12	0.00	1.67	1.14	0.13	0.57	0.50	1.20	1.95	1.75	1.35	1.57
Chydorus sphaericus	CCHSP	10.93	19.70	8.77	14.02	11.99	8.47	4.44	6.42	9.49	7.85	7.38	4.52
Daphnia longispina/hyalina	CDALH	1.33	4.66	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurycercus lamellatus	CEULA	1.41	0.88	0.16	0.52	0.42	0.00	0.06	0.05	0.00	0.00	0.03	0.37
Graptolebris testudinaria	CGRTE	0.12	0.88	0.00	0.83	0.33	0.20	0.55	0.10	1.08	0.07	1.35	0.79
Leydigia acanthocercoides	CLEAC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.06	0.00	0.02	0.00
Leydigia leydigii	CLELI	0.28	0.88	0.56	0.52	0.84	0.73	0.77	2.34	3.90	3.09	2.44	2.86
Monospilus dispar	CMODI	1.33	0.78	0.48	0.00	0.35	1.09	0.11	0.00	0.06	1.41	1.80	2.57
Phiruxa rostrata	CPHIR	1.33	0.78	0.16	0.47	0.71	0.36	0.55	1.00	3.23	2.22	2.79	3.30
Pleuroxus laevis	CPLLA	1.33	0.10	0.72	0.09	0.42	0.00	0.22	0.00	0.00	0.34	0.47	0.00
Pleuroxus truncatus	CPLTR	0.00	0.05	0.95	0.56	0.00	0.00	0.55	0.50	0.00	0.00	0.02	0.00
Pleuroxus uncinatus	CPLUN	0.45	0.88	0.47	0.70	0.73	0.32	1.43	1.20	1.30	1.32	1.35	2.66
Rhynchotalona falcata	CRHFA	0.00	0.00	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sida crystalina	CSICR	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.45	0.00
Cyclops	CYCL	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 4 DATA USED IN THE MACROPHYTE-NUTRIENT MODELS

	pre-1900 (historical records)					*post-1990 (contemporary vegetation surveys)*					*relative change*		
	macrophyte-inferred TP	LMNI	calibrated TP	l_CL	U_CL	macrophyte-inferred TP	LMNI	calibrated TP	L_90CL	U_90CL	macrophyte-inferred TP	LMNI	calibrated TP
Abbots Moss Hall Pond	51	3.29	48	20	114	63	4.77	80	33	190	1.22	1.45	1.66
Alkmund Park Pool	58	5.73	64	27	153	56	6.23	60	25	143	0.97	1.09	0.93
Aqualate Mere	46	6.52	37	16	89	100	7.25	421	173	1018	2.19	1.11	11.27
Berrington Pool	43	5.21	33	14	78	70	6.39	113	47	271	1.65	1.23	3.46
Betley Mere	30	4.63	18	8	43	98	7.39	395	162	955	3.31	1.60	21.55
Betton Pool	29	5.46	18	8	42	73	6.77	128	53	307	2.51	1.24	7.19
Blake Mere	42	5.67	32	13	76								
Bomere Pool	47	5.32	39	16	93	64	6.00	85	35	204	1.37	1.13	2.19
Budworth Mere	92	8.11	303	124	729								
Cole Mere	34	5.67	22	9	52	72	7.10	123	51	296	2.14	1.25	5.63
Comber Mere	***51***	***6.18***	***47***	***20***	***112***	94	7.15	317	130	766	***1.84***	***1.16***	***6.72***
Cop Mere	99	8.03	397	163	959	93	7.47	313	129	754	0.95	0.93	0.79
Crose Mere	29	5.84	17	7	41	81	7.02	178	73	426	2.81	1.20	10.15
Fenemere	61	6.32	75	31	179	67	6.83	98	41	235	1.10	1.08	1.31
Hatch Mere	45	4.94	37	15	87	64	6.51	83	35	199	1.41	1.32	2.28
Llynclys Pool	51	5.96	48	20	114	147	6.07	3434	1381	8415	2.87	1.02	72.01
Maer Pool	37	5.46	25	10	59	86	6.98	226	93	543	2.35	1.28	9.07
Marton Pool, Baschurch	63	5.74	81	34	193	65	7.62	88	36	210	1.03	1.33	1.09
Marton Pool, Chirbury	70	7.40	112	46	267	82	7.15	188	78	451	1.17	0.97	1.68
Melchett Mere	***68***	***7.05***	***103***	***43***	***246***	87	7.01	237	98	571	***1.27***	***1.00***	***2.31***
Mere Pool	85	7.85	221	91	532								
Newton Mere	48	4.33	42	17	99								
Oak Mere	69	3.94	108	45	257	58	6.12	64	27	153	0.83	1.55	0.60
Oss Mere	38	5.74	27	11	64	94	7.15	324	133	780	2.45	1.25	12.04
Oxon Pool	31	4.95	20	8	46	129	6.84	1568	635	3822	4.13	1.38	79.97
Pick Mere	62	7.84	79	33	188								
Quoisley Meres	72	7.14	122	51	293	65	6.92	88	36	210	0.90	0.97	0.72
Redes Mere	82	8.45	192	79	460								
Rostherne Mere	48	6.17	42	17	99	80	6.76	174	72	417	1.66	1.10	4.15
Shomere Pool	21	3.94	12	5	29	71	6.63	115	48	277	3.43	1.68	9.45
Shrawardine Pool	54	6.46	55	23	130	99	7.00	404	166	976	1.83	1.08	7.39
Tabley Mere	79	7.09	167	69	400	87	7.29	241	99	580	1.10	1.03	1.45
Tatton Mere	***68***	***7.05***	***103***	***43***	***246***	76	7.16	147	61	353	***1.12***	***1.02***	***1.43***
The Berth	51	6.62	47	20	112	79	6.81	166	69	399	1.55	1.03	3.52
The Mere, Ellesmere	68	6.37	101	42	243	83	6.96	197	81	473	1.22	1.09	1.94
The Mere, Mere	59	6.02	69	29	165	72	6.65	121	50	289	1.21	1.11	1.75
Walford Pool	67	5.13	96	40	229	80	7.16	172	71	413	1.20	1.39	1.80
White Mere	47	5.86	39	16	93	76	6.77	147	61	353	1.63	1.16	3.75
Willey Ponds	45	6.56	36	15	85	83	7.58	196	81	471	1.85	1.16	5.45