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Reconstructing the macrophyte flora of three Broads: A palaeolimnological analysis

Report to the Broads Authority

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Cover Photo – Little Broad (Daniel Hoare)

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Study Rationale

The decline in ecological quality and conservation value of Europe fresh waters is an all too common phenomenon. In lowland Britain the main anthropogenic impact on the river aquatic systems is that associated with elevated nutrient loading. The Broads are internationally important wetlands spanning a number of river basins in East Anglia. The Broads have suffered along with other wetlands and eutrophication has had a deleterious effect on the system (Mason & Bryant 1975, Moss 1977). There has been a general decline in the ecological quality and conservation value of the Broads as a result of eutrophication, with one of the main symptoms being elevated algal productivity. One of the changes in the ecological structure and functioning of shallow lakes in response to enrichment is an alteration in their macrophyte flora (Ris & Sand-Jensen 2001) and in extreme cases there may be the complete loss of submerged plants (Scheffer *et al*. 1993). The loss of the diversity of the macrophyte flora in the Broads is one of the contributing factors to the decline in their conservation value.

Standing water bodies are ephemeral features of the landscape as they naturally fill-in with sediment. Increases in primary production caused by elevated nutrient levels accelerate this process. Thus, the life-span of enriched Broads may be greatly reduced as accumulation rates increase from perhaps < 1 mm yr^{-1} under low nutrient conditions to 1 cm yr^{-1} under very eutrophic conditions. Furthermore, under oxidised conditions lake sediments act as a sink for phosphorus, one of the key agents of eutrophication. Increased primary productivity can result in de-oxygenation at the sediment surface which reverses its capacity to bind to phosphorus resulting in its release into the water, which increases enrichment still further. The removal of the accumulated sediment from the Broads has, therefore, been seen as an appropriate method of lake restoration as it both increases water depth and removes a source of phosphorus (e.g. Moss *et al.* 1996a). A number of Broads have had their sediments removed as part of their management, for example Cockshoot (Moss *et al*. 1996b), Strumpshaw, Cromes and Barton Broads. This study sought to inform management of Little, Cromes and Upton Little Broads with particular reference to sediment removal through the analysis of plant and animal remains the sediment cores.

Study Aims

The study had two main aims:

1. To determine the former macrophyte communities of the three Broads and to assess the degree and timing of any shifts in the past macrophyte flora.

2. To assess the appropriateness of sediment removal as a restoration measure.

Methods

Coring

Sediment cores were extracted using an adapted Livingstone type piston corer (Livingstone 1955) from Little Broad, Upton Little Broad and Cromes Broad on the 12th and 13th of September 2005. The cores were coded LILT1 (Little Broad), CROM1 (Cromes Broad) and UPTL1 (Upton Little Broad) and were 120 cm, 146 cm and 134 cm in length respectively. The cores were extruded at 1 cm intervals in the field and the main characteristics of the sediment and any stratigraphic changes were noted.

Radiometric dating
^{210}Pb (half-life = 22.3 years) is a naturally-produced radionuclide that has been extensively used in the dating of recent sediments. Dating is based on determination of the vertical distribution of ^{210}Pb derived from atmospheric fallout (termed unsupported ^{210}Pb, or $^{210}Pb_{excess}$), and the known decay rate of ^{210}Pb (see Appleby and Oldfield 1992 for further details of the ^{210}Pb method). ^{137}Cs (half-life = 30 years) is an artificially produced radionuclide, introduced to the study area by atmospheric fallout from nuclear weapons testing, and nuclear reactor accidents. Global dispersion of ^{137}Cs began in AD 1954, with marked maxima in the deposition of ^{137}Cs occurring in AD 1958, AD 1963 (from nuclear weapons testing) and AD 1986 (from the Chernobyl accident). For the latter, the majority of the fallout of ^{137}Cs occurred in the north and west of the UK, with the south and east receiving comparatively little fallout (e.g. Cambray et al 1987, Watt Committee on Energy, 1991). In favourable conditions, periods of peak fallout/discharge provide subsurface activity maxima in accumulating sediments which can be used to derive rates of sediment accumulation (e.g. Ritchie *et al*., 1990; Cundy and Croudace, 1996).

Core sub-samples were counted on a Canberra well-type ultra-low background HPGe gamma ray spectrometer to determine the activities of ^{137}Cs, ^{210}Pb and other gamma emitters. Spectra were analysed using the Genie 2000 system, and accumulated using a 16K channel integrated multichannel analyzer. Energy and efficiency calibrations were carried out using bentonite clay spiked with a mixed gamma-emitting radionuclide standard, QCYK8163, and checked against an IAEA marine sediment certified reference material (IAEA 135). Detection limits depend on radionuclide gamma energy, count time and sample mass, but were typically *ca.* 20 Bq/kg for ^{210}Pb, and 4 Bq/kg for ^{137}Cs and ^{241}Am, for a 150,000 second count time.

Macrofossil analysis
In the absence of reliable historical information on past aquatic macrophyte communities, analysis of sedimentary macro-remains of plants (the seeds, fruits and remains of stems, leaves and rhizomes) may provide a technique for determining changes in the aquatic flora of a site (Birks 1980). Recent work has indicated that plant macrofossils provide a reliable means for tracking shifts in the dominant components of the submerged aquatic flora in shallow lakes (Davidson *et al*. 2005).

In this study 15 levels from UPTL1 and LITL1 and 14 from CROM1 were examined for macrofossils. A comparatively large volume of sediment was analysed (between 42 and 65 cm^3) by amalgamating adjacent 1 cm slices. The surface sample of a core generally has a high proportion of water and therefore contains less plant material, thus the top-most sample analysed here was the 1-3 cm section. Samples were sieved at 350 and 125 microns, the exact sample volume being measured by water displacement. The entire residue on the 350 micron sieve was examined under a stereo-microscope at magnifications of X10-40 and plant and animal macrofossils were enumerated. A quantitative sub-sample, approximately one tenth of the sample, from the 125 micron sieve was analysed for smaller remains, such as leaf spines. All material was identified by comparison to reference material. It is not always possible to ascribe remains to species level, thus in some cases an aggregate groups of species corresponding to the highest possible taxonomic resolution was used. For example, *Potamogeton* leaf remains were grouped as *Potamogeton pusillus* agg. which included *P. pusillus* and *P. berchtoldii*. Distinct morphotypes of *Chara* oospores were also identified. The data are presented as numbers of remains per 100 cm^3 of wet sediment.

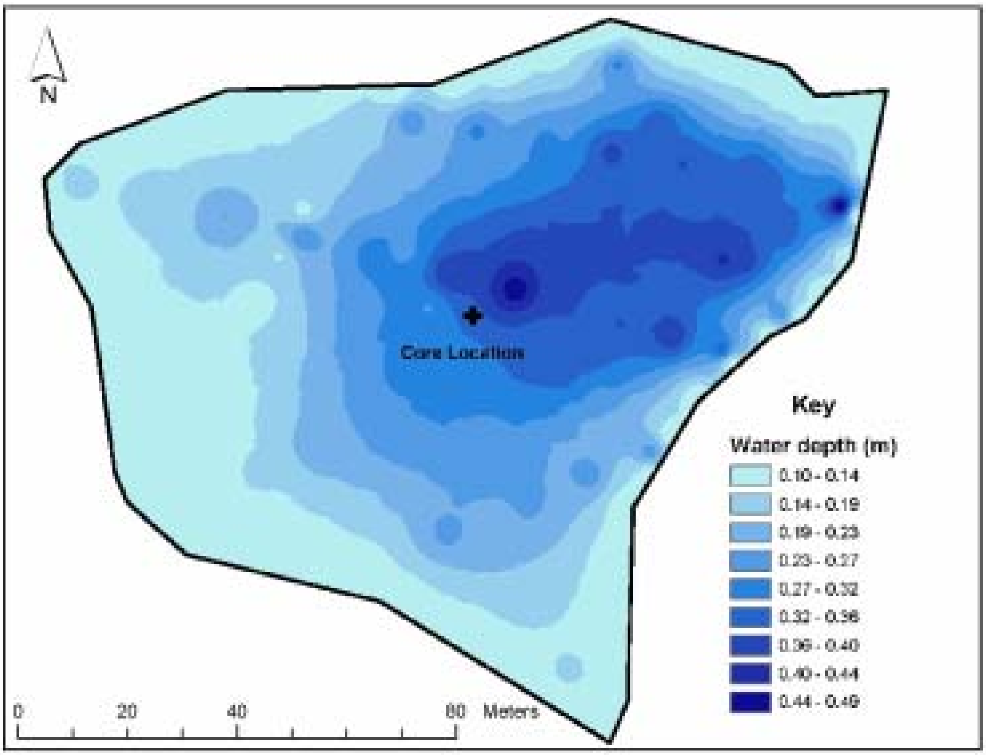
Cluster analysis was performed on both plant and animal macrofossil data to facilitate the description of zones for all three cores. A variety of constrained clustering techniques were employed using the program ZONE (Juggins 1991). All clustering techniques have weakness and in certain circumstances provide misleading zones. In order to obviate this problem the results of a number of methods were compared and only the patterns which were consistent in a number of the techniques were employed.

Results

Little Broad

Site and core description
Little Broad (TG 449 129) is a small (1 ha), extremely shallow (max. depth 49 cm) lake which forms part of the Trinity Broads system. A detailed lake bathymetry, with the core location is given in Figure 1. There was, in general, very little variation in water depth which varied from shallow to very shallow, the deepest area lying to the north east of the lake centre. Currently the Broad does not support any submerged vegetation.

Figure 1. Bathymetric map of Little Broad



Core chronology
The extremely low unsupported ^{210}Pb activity in the sediments of LILT1 precluded dating by the ^{210}Pb method. ^{210}Pb activity declined below detection limits at depths greater than 5 cm despite extended count times. The ^{137}Cs profile, however, had a well defined maximum at 3.5 cm, which is likely to correspond to the 1963 weapons fallout peak, (NB. This subsurface maximum is unlikely to be a result of fallout from the Chernobyl accident in 1986 due to the relatively low levels of Chernobyl fallout received in the study location – see methods), indicative of an accumulation rate of c. 1mm y^{-1} during the last 40 years. The extrapolation of this accumulation rate further back into to the record would rely on the assumption of a uniform accumulation rate. This assumption is very unlikely to have been met and thus the only dating used has been the ^{137}Cs peak.

of any seeds it is difficult to definitively ascribe a species to the *Ceratophyllum* remains. It is likely, however, that they were *C. demersum* rather than the rarer *C. submersum*. The last sample in zone 1 had a slight increase in *Nitella* oospores which had very low numbers in the bottom two samples, and the first appearance of *Stratiotes aloides* leaf spines.

At the boundary between zones 1 and 2 (77 cm) there was a transition in the assemblage with a decline in the numbers of *Chara* oospores and *Ceratophyllum* spines and an increase in *S. aloides* spines and *Nitella* oospores. Zone 2 had the greatest diversity of remains, with *Nymphaea alba* seed fragments, *Zanichellia palustris* seeds and *P. friesii* leaf fragments in addition to low numbers of *Chara* oospores and *Ceratophyllum* leaf spines. Towards the top of zone 2 the abundance and diversity of remains of all submerged species fell. In zone 3 (33-0 cm) the macrofossil assemblage was dominated by the emergent species of *Typha* spp. and *Juncus* spp. A single sample in the zone contained very low numbers of *Nitella* oospores and *Z. palustris,* but in general there was an almost total absence of remains of submerged or floating leaved macrophytes.

Animal remains

The constrained clustering of the animal macrofossil assemblage produced exactly the same zonations as that based on plant remains.

In zone 1 the remains of fish in the form of scales were relatively diverse, with percid, cyprinid and pike (*Esox lucius)* all represented. Macro-invertebrate remains were abundant, with high numbers of *Orthotrichia* spp., undifferentiated Trichopteran and the cocoons of the fish leech *Piscicola geometra*. The cladoceran community was characterised by the absence of ephippia from large-bodied pelagic species, such as *Daphnia*, and the consistent presence of *Simocephalus* spp. Additionally, the over-wintering statoblast of the bryozoan *Cristatella mucedo* were numerous in all samples whereas those of *Plumatella* spp., whilst present in all samples varied more in their abundance. Molluscs were represented by the operculae of *Bithynia tentaculata* only.

In Zone 2 (77-33 cm) percid fish scale remains were consistently present and abundant. Trichopteran cases became less numerous, in particular *Orthotrichia* spp. declined to towards the top of the zone. Similarly *P. geometra* cocoons numbers fell gradually during at this time. As in the lower section of the core pelagic cladocerans were relatively rare, but towards the top of the zone *Daphnia magna* occurred more consistently, albeit in low numbers, as did *Daphnia hyalina* agg. and *Ceriodaphnia* spp. The numbers of the ephippia of *Leydigia* spp. remained fairly constant through the zone. The abundance of statoblasts of the bryozoans *C. mucedo* and *Plumatella* spp. fell sharply, the latter being only sporadically present in zone 2. Those of the rarer bryozoan species *Lophopus crystallinus* were found in this section of the core. In zone 2 *B. tentaculata* remains disappeared whereas those of *Pisidium* spp. appeared and slightly increased towards the top of the zone.

In zone 3 (33-0 cm) the abundance of percid scales fell, pike were absent and cyprinids were also rare. Trichopteran cases, of all species, were almost entirely absent. The abundance of pelagic cladoceran, in particular *D. magna* and *D. hyalina* agg., ephippia increased markedly at the top of the core, whereas the mud-associated *Leydgia* spp. and plant-associated *Simocephalus* spp. showed very little variation.

Figure 3. Summary stratigraphy for selected plant macrofossils for the core LILT1 from Little Broad

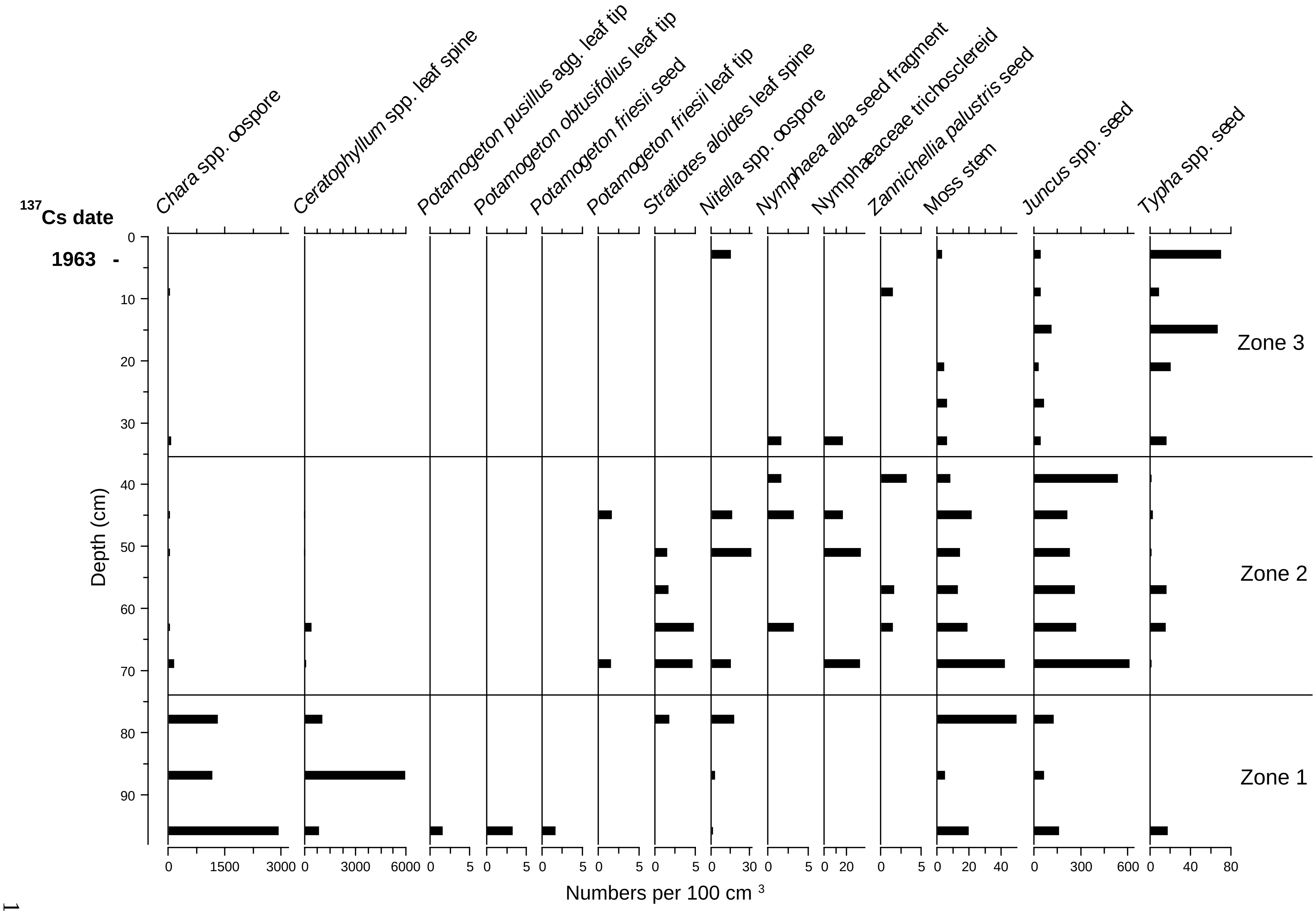


Figure 4. Summary stratigraphy of animal macrofossil for the core LILT1 from Little Broad

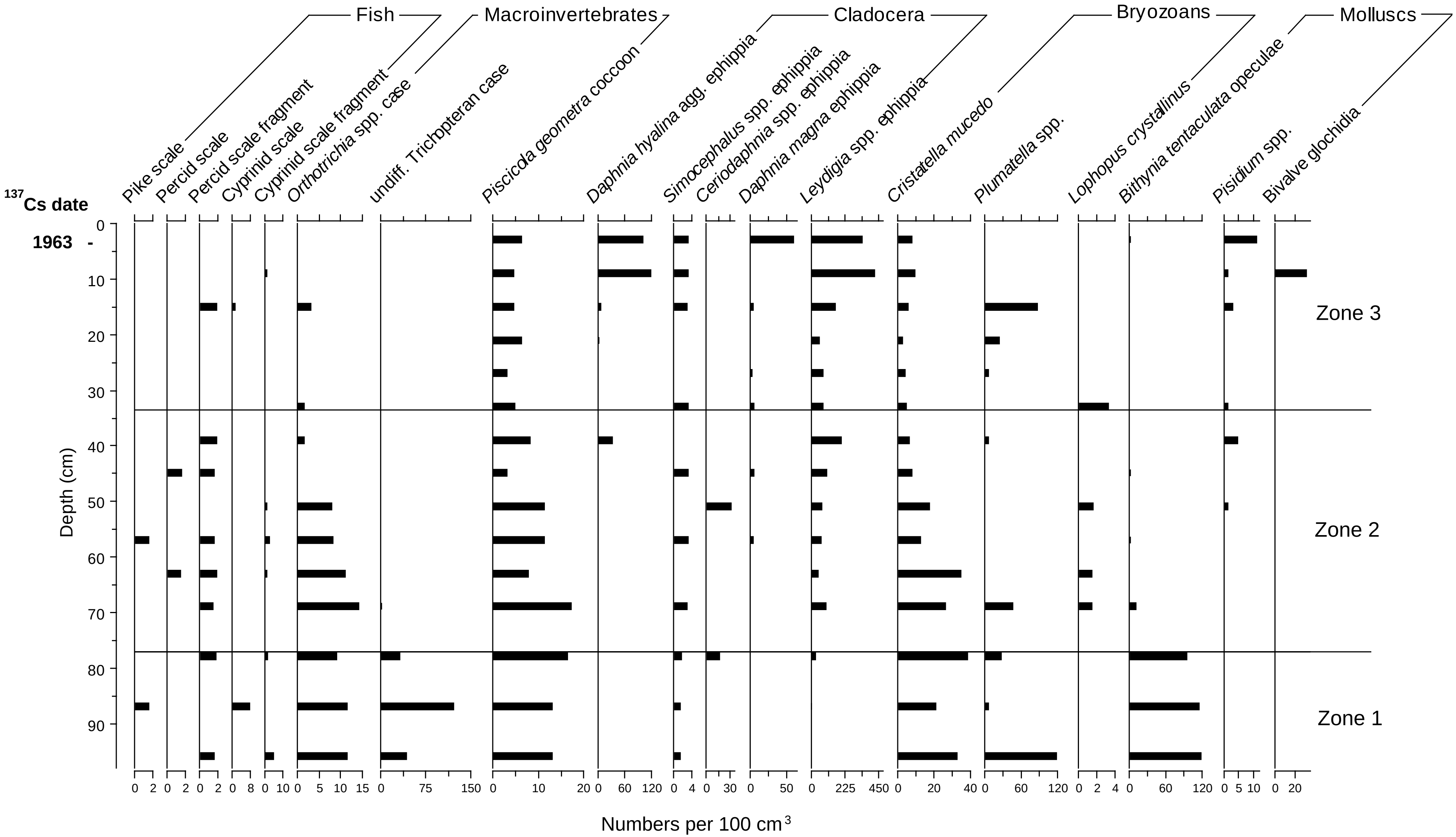


Figure 2. Stratigraphy of LILT1

Depth (cm)	Sediment colour
0-40	**Grey-brown**
41-61	**Light-brown**
62-80	**Mid-brown**
81-89	**Light brown**
90-100	**Mid-brown**
101-119	**Peat**

The core LILT1 was taken from the centre of the site (Fig. 1) at a water depth of 39 cm. There were a number of notable stratigraphic features (Fig. 2). The base of the sequence was peat indicating that the entire lacustrine period of Little Broad was covered by the core. Thus, 119-101 cm represents a period prior to the flooding of the peat diggings and the formation of the Broad. The remainder of the core was made up of true lake sediments with relatively distinct changes in sediment colour (Fig. 2).

Macrofossil data

The complete results of the macrofossils analysis of core LILT1 are given in Appendix 1. Figure 3 comprises a selection of fossils of generally submerged species which summarise the major floristic changes along the length of the core. Shifts in the animal macrofossil remains, in this case fish, macro-invertebrates, cladocerans, bryozoans and molluscs can be seen in Figure 4. There were three main zones in both the plant and animal remains data, reflecting two significant shifts in assemblages.

Plant remains

The base of the sequence, zone 1 (98–77 cm), was dominated by high numbers of *Chara* oospores of one main morphotype. The bottom sample contained around 3000 oospores per 100 cm^3 of sediment, a high number which suggests the existence of extensive *Chara* meadows in the Broad at this time (Zhao *et al*. 2006). The bottom sample also had remains of three *Potamogeton* species, *Potamogeton obtusifolius*, *Potamogeton friesii* and *Potamogeton pusillus* agg. In the adjacent sample no *Potamogeton* remains were found, charophyte oospore abundance fell and there was an increase in *Ceratophyllum* spp. spine numbers from around 900 to 6000 per 100 cm^3. In the absence

Cromes Broad

Site and core description

Cromes Broad (TG 374 196) is a side valley Broad in the Ant system. It is small (3.7 ha) and has two sections, this study focussed exclusively on the recently dredged northern section. The north section had a maximum and mean depth of 86 cm and 58 cm respectively prior to dredging. The Broad is now deeper in the central area but the lake margins were left un-dredged and CROM1 was extracted from one these un-dredged areas to the northern end of the Broad. Prior to dredging the Broad had a relatively depauperate macrophyte flora which in 2000 was dominated by *Ceratophyllum demersum, Lemna minor* and various types of filamentous algae (Sayer & Davidson unpublished data). In 1999-2000 the Broad had annual mean nutrient concentrations of 0.58 mg l^{-1} NO_3^--N and 249 µg l^{-1} TP (Sayer unpublished data).

Figure 5. Stratigraphy of CROM1

Depth (cm)	Sediment colour
0-60	**Mid-brown**
61-100	**Chestnut-brown**
101-120	**Grey-brown**
121-149	**Peat**

The core CROM1 was 149 cm long and was taken at a water depth of 44 cm. The stratigraphy of the core was relatively homogenous and in comparison to the other cores in this report the colour changes were very subtle. The base of the core consisted of peaty material, although less firm in texture than the bottom of the other cores which formed part of this study. This combined with the fact that remains of aquatic species were extremely rare in the sample at 139-141 cm indicated that the sequence covers the entire lacustrine period of the Broad. The peat-type sediment that occurred at the core bottom gave way to grey-brown sediment at around 100 cm with a further change to chestnut brown at 60 cm. There is then a final shift in sediment type to a homogenous mid-brown from approximately 60 cm to the surface of the core.

Core chronology

As for LILT1 the ^{210}Pb activity for CROM1 was very low and was only above the detection limits in one sample. Thus, it was not possible to establish a chronology employing ^{210}Pb. The ^{137}Cs profile observed in this core was relatively erratic in comparison to that observed in LILT1. There was no clearly defined subsurface activity maximum. Instead, there is a relatively broad maximum between -1 and -7 cm depth. As in LILT1, the bulk of the ^{137}Cs activity is confined to the upper 10cm of the core. Thus, it was not possible to calculate a precise sediment accumulation rate using this profile, although based on the broad subsurface maximum present, a rate of 1.8mm a^{-1} or less can be estimated (again, assuming that the activity maximum observed corresponds to the 1963 peak fallout event from nuclear weapons testing).

Macrofossil data

The complete data set of all macrofossils found in CROM1 is given in Appendix 2. Figures 6 and 7 are summaries of the stratigraphy of the plant and animal remains respectively. The species plotted in the diagrams were selected on the grounds of abundance and relevance to the investigation.

Plant remains

The constrained cluster analysis of the plant remains produced three zones. Zone 1 (129-91 cm) had a diverse submerged plant macrofossil assemblage compared not only to the other cores in this study but also other investigations (e.g. Davidson *et al*. 2005). There was some variation in the assemblages between the lower and upper part of zone 1. The basal two samples had abundant *Nitella* oospores which declined then disappeared above 100 cm. The charophyte assemblage was dominated by *Chara* spp. 1 which had relatively high abundances throughout the zone, becoming the dominant charophyte after the disappearance of *Nitella* oospores. Particularly notable is the presence of a single seed of *Myriophyllum alterniflorum* at the base of the sequence. Other important species represented by remains in zone 1 were *Chara* spp. 3, albeit in relatively low numbers, along with a diverse array of *Potamogeton* species, including *P. pusillus* agg., *P. obtusifolius*, *P. friesii* and *P. praelongus*. Furthermore, *Ranunculus* sect. *Batrachium* was found towards the top of the zone.

Zone 2 (90-46 cm) saw a shift away from numerous *Chara* and *Potamogeton* remains to the dominance of those of *N. alba* and *Ceratophyllum*. Towards the top of zone 2 there was a further shift as the numbers of the leaf spines of *S. aloides* increased and those of *Ceratophyllum* fell. In the bottom two samples of the zone the remains of the colonial blue-green algae *Gloetrichia* were numerous.

Zone 3 (45-1 cm) had a depauperate assemblage with both a low diversity and abundance of remains. There was a decline in the number *Ceratophyllum* leaf spines with relatively few present in the uppermost sample. Spines of *S. aloides* also declined and then disappeared, there was a single *Lemna minor* leaf found in the top sample. *N. alba* seed fragments were still present but Nymphaeaceae trichosclereids were absent from zone 3.

Animal remains

Cluster analysis of the animal remains produced very similar zones to the plant remains. Zone 1 (129-91 cm) had a relatively low diversity of remains. Oribatid mites were, however, abundant and *Orthotrichia* spp. was consistently present. *D. pulex* and *D. hyalina* agg, occurred sporadically and in low numbers as did the smaller *Ceriodaphnia* spp. The ephippia of the benthic cladocerans *Camptocercus rectirostris, Simocephalus* spp and Chydoridae were occasionally present. In zone 1 *C. mucedo* and *Plumatella* statoblasts were present in all samples and in relatively high numbers, whereas *Lophopus crystallinus* statoblast appeared only in the basal sample.

Zone 2 (90-46 cm) had a relatively diverse assemblage. There were three different types of trichopterans, oribatid mites were again numerous and the cocoons of the fish leech *P. geometra* were abundant. Cladocerans also became more numerous with *D. pulex* numerically dominating the pelagic cladoceran assemblage. *D. hyalina* and *Ceriodaphnia* spp were consistently present albeit in low numbers. Similarly, plant and mud associated species were better represented in this zone, with more chydorid ephippia and the (re)appearance of *Simocephalus* spp. and *Leydigia* spp. Both *C. mucedo* and *Plumatella* spp. increased to very high abundances.

Zone 3 (45-0 cm) saw a sharp drop in the number all trichopteran cases. Oribatid mites persisted in reduced numbers as did the cocoons of *P. geometra*. There was a loss of *D. pulex* whereas *D. hyalina* and *Ceriodaphnia* spp. persisted. The ephippia of the benthic taxa *Simocephalus* spp., chydorids and *Leydigia* spp. significantly rose in number. In contrast, numbers of the statoblasts of *C. mucedo* fell sharply and those of *Plumatella* declined slightly and the remains of the much rarer *L. crystallinus* (re)appeared in the record. A number of mollusc remains appeared in zone 3, in particular the glochidia of the swan mussel (*Anodonta cygnea*) and *Pisidium* spp in very low numbers.

Figure 6. Summary stratigraphy of plant remains for the core CROM1 from Cromes Broad

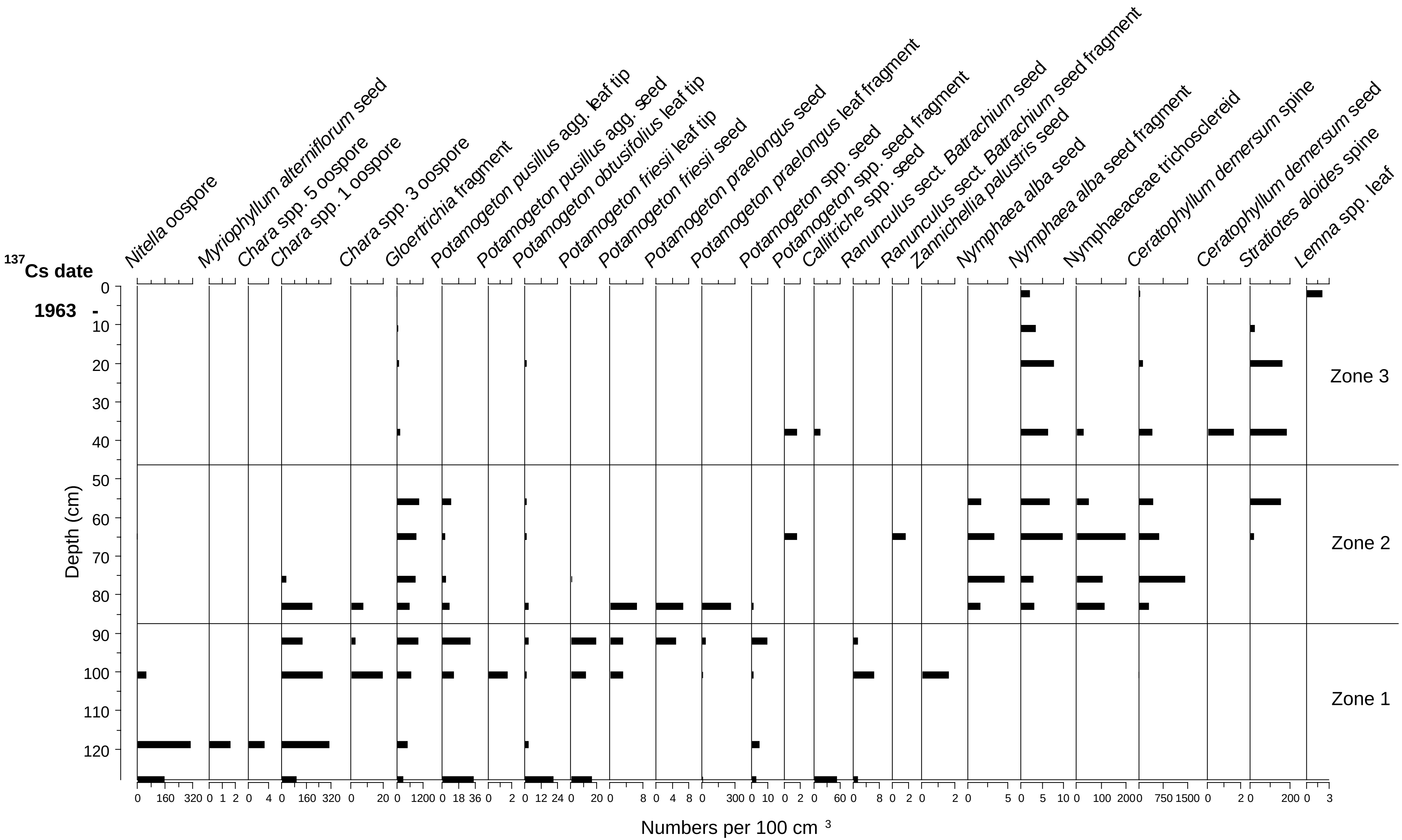
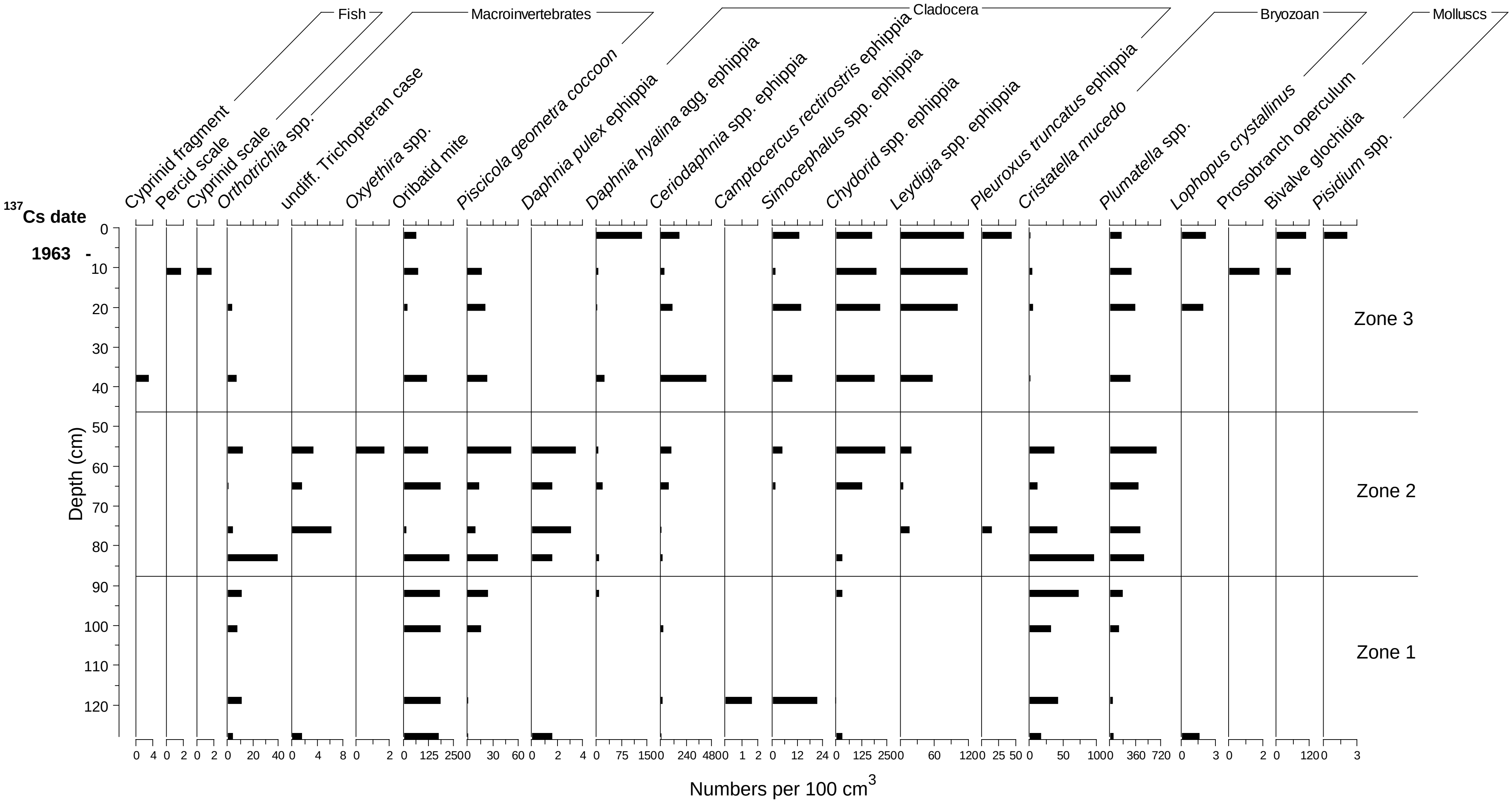


Figure 7. Summary stratigraphy of animal remains for the core CROM1 from Cromes Broad



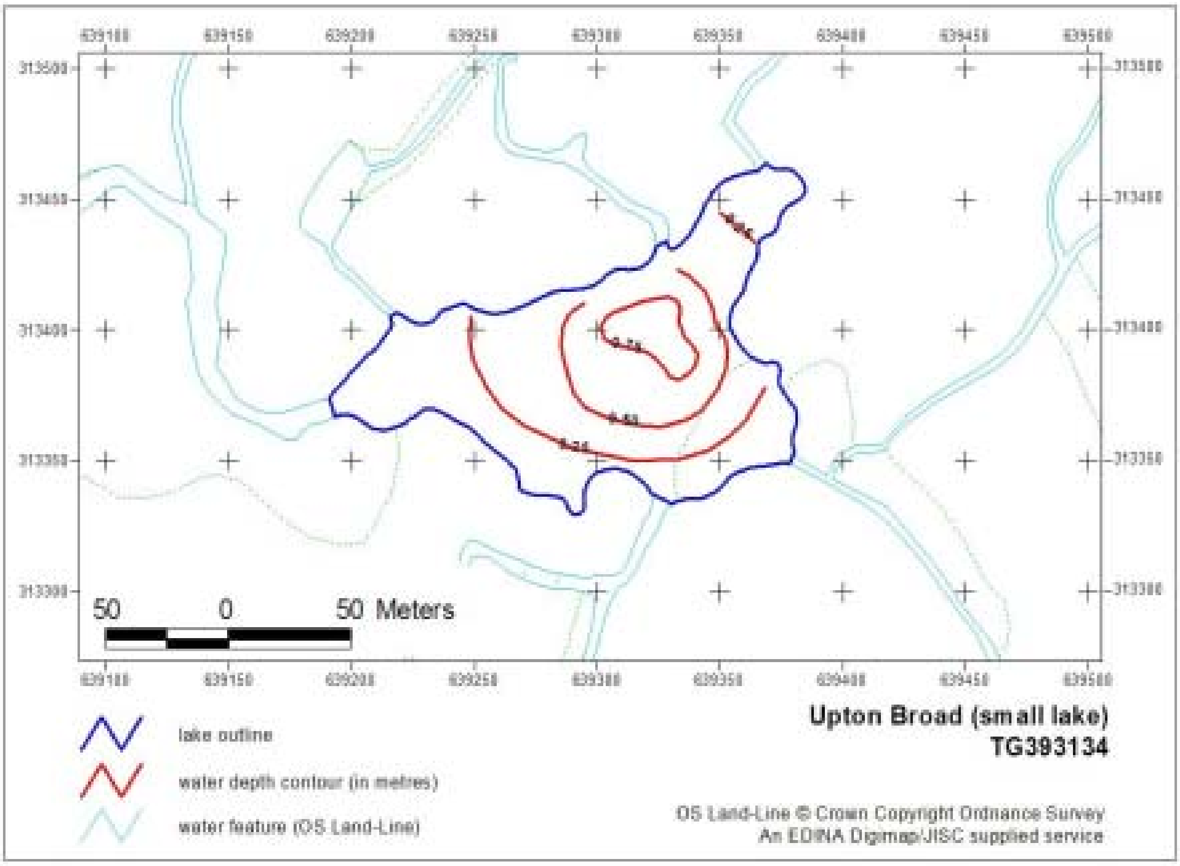
Upton Little Broad

Site and core description

Upton Little Broad (TG 393 133) is a side valley broad in the Bure system. It is small, (2.2 ha) and shallow with a maximum depth of around 75 cm.

The bathymetry (Fig. 8) was produced as a part of a previous study (Skeate *et al*. 2004). Upton Little Broad is generally very shallow but deepens to over 75 cm just east of the centre of the Broad. An assessment of the macrophyte flora was made as part of the coring exercise. The site was dominated by *Najas marina* which was abundant. *Chara contraria*. and *Potamogeton pectinatus* were also present but had lower abundances. Also numerous were colonial algal balls which occupied a relatively large area of the sediment surface, particularly in the shallow areas to the west of the Broad. These colonial algae were previously identified as *Aphanocapsa* spp. (Skeate *et al*. 2004).

Figure 8. Bathymetry of Upton Little Broad



Core chronology

The ^{210}Pb activity in UPTL1 was significantly higher than at the other two sites, it was, however, undetectable below 10 cm. Thus, whilst levels were higher than at the other sites it was still not possible to establish a ^{210}Pb based chronology. Once again, however, ^{137}Cs showed a distinct subsurface maximum in activity at -6 to -7 cm depth and declined to activities below detection limits at -12 cm depth. Activities observed are relatively low (in comparison with the other cores dated), presumably due to the relatively carbonate-rich nature of the sediment in this core (large numbers of shell fragments were present under visual examination). 137Cs shows high affinity for clay-rich sediments, and the presence of large amounts of carbonate material will tend to reduce the observed activities, effectively “diluting” any 137Cs present (e.g. Cundy et al 2002). Assuming that the activity maximum at -6.5 cm corresponds to the period of peak fallout of 137Cs from above-ground nuclear weapons testing in 1963, then a sediment accumulation rate of 1.5 – 2 mm a-1 is indicated.

Figure 9. Stratigraphy of UPTL1

Depth (cm)	Sediment colour
0-10	**Green ooze**
11-50	**Mid-brown marl**
51-100	**Light-brown marl**
100-110	**Mid-brown marl**
111-135	**Peat**

The core UPTL1 was 135 cm long and was taken at a water depth of 50 cm. There were a number of marked changes in sediment composition along the length of the core. The base was peat and therefore the sequence represents the entire life of the Broad with the peat probably corresponding to the time of initial flooding. At 110 cm there was a relatively sharp change from peat to mid-brown marl, which at approximately 100 cm shifts into light-marl. This colour persisted to 51 cm where there was a change back to a mid-brown colour. The final change was a shift to a green ooze. The sediments in the top 10 cm of the core have a flocculent quality with a high water content. These sediments are very similar to those at the surface of Upton Great Broad where the faecal pellets of chironomids which have fed almost exclusively on the colonial blue green algae *Aphanothece* spp. dominate the sediment structure.

Macrofossil data

The complete data set of all macrofossils found in UPTL1 is given in Appendix 3. Owing to the extremely high abundance of remains found in UPTL1 the results are displayed in three separate Figures. Figure 10 is the summary stratigraphy of selected plant remains, Figure 11 the combined mollusc and cladoceran stratigraphy and Figure 12 a summary stratigraphy of fish, invertebrate and bryozoan remains.

Plant remains

The constrained clustering produced four distinct zones. Zone 1 (110-96 cm) contained five distinct morphotypes of *Chara* oospore, at relatively low numbers along with a *N. marina* seed and *Sphagnum* leaves. Zone 2 (95-84 cm) contained almost no macrofossil remains, with just *Chara* oospore spp. 3 represented in one sample. The only other remain in zone 2 were unidentified orange gelatinous matter, which most resemble some form of colonial algae and were extremely abundant.

Zone 3 (84-26 cm) had a relatively diverse plant macrofossil assemblage with all five morphotypes of *Chara* oospore present in addition to *S. aloides*, *R.* sect *Batrachium*, *N. alba* and at least two species of *Potamogeton*. There were, however, some changes within zone 3 with *N. marina* fleetingly present at the base of the zone before disappearing. The top of zone 3 saw the appearance of a number of species including, Nymphaeaceae, *R.* sect. *Batrachium*, *Chara* spp. 1 and spp. 5 along with *Z. palustris*.

Zone 4 (25 cm to the surface) was characterised by a decline in species richness and a shift to the dominance of *N. marina* leaf spines, *Z. palustris* seeds and *Chara* spp. 1 and spp. 5 oospores.

Animal remains

Mollusc remains were both numerous and diverse in UPTL1 (Fig. 11). The zonations based on mollusc and cladoceran remains was identical to the plant remain based zonations. Zone 1 contained a rich array of mollusc shells. There were few cladoceran ephippia with only low numbers of *Simocephalus* spp. and *Leydigia* spp., which are associated with plants and mud respectively. Fish remains indicated the presence of both percid and cyprinid fishes and bryozoan statoblasts were generally absent from the lower part of the core (Fig. 12).

In keeping with the plant data animal remains were rare in zone 2 (95-84 cm). Mollusc shells were entirely absent with only the operculae of *Bythinia* present. Low numbers of chydorid, *Leydigia* and *Ceriodaphnia* ephippia were found and fish scales were absent. There was a very similar pattern for the *Orthotrichia* and *P. geometra* remains.

Zone 3 (84-31 cm) had a much more diverse assemblage with 16 species of molluscs represented. There was a general trend up-core with the decline and loss of *Bythinia* and *Lymnea peregra* respectively. In contrast, other species, including *Gyraulus crista*, *Physa* spp., *Planorbis vortex* and *Acroluxus lacustris* increased in number or appeared towards the top of zone 3. Cladoceran remains showed a general shift from benthic to pelagic species as chydorid and *Leydigia* spp. ephippia numbers fell and those of *D. magna*, *D. hyalina* and *Ceriodaphnia* rose. Above 79 cm fish remains were not particularly abundant, but percid scales were consistently present. A single whole bream scale was found at the top of this zone. *Orthotrichia* spp. cases appeared at the base of the zone then numbers declined sharply. *P. geometra* cocoons were abundant throughout zone 3 as were oribatid mites. Bryozoans were common at this time with *C. mucedo* and *Plumatella* consistently present and *L. crystallinus* appearing in one sample at the base of zone 3.

Zone 4 (17 cm and the surface) had many fewer mollusc remains. The species characteristic of zone 3 were *H. complanata*, *Planorbis albus* and *V. cristata* with *Pisidium* spp. and the operculae of prosobranch species also present. The cladoceran assemblage displayed relatively large shifts with a dramatic increase in numbers of pelagic species, *D. magna*, *D. hyalina* and *Ceriodaphnia*, though the later was absent from the uppermost sample. Both cyprinid and percid scales were present in this zone. Macroinvertebrate remains were scarce with only oribatid mites consistently present. *C. mucedo* and *Plumatella* spp. were present in lower numbers than zone 3.

Figure 10. Summary stratigraphy of Plant remains of UPTL1 from Upton Little Broad

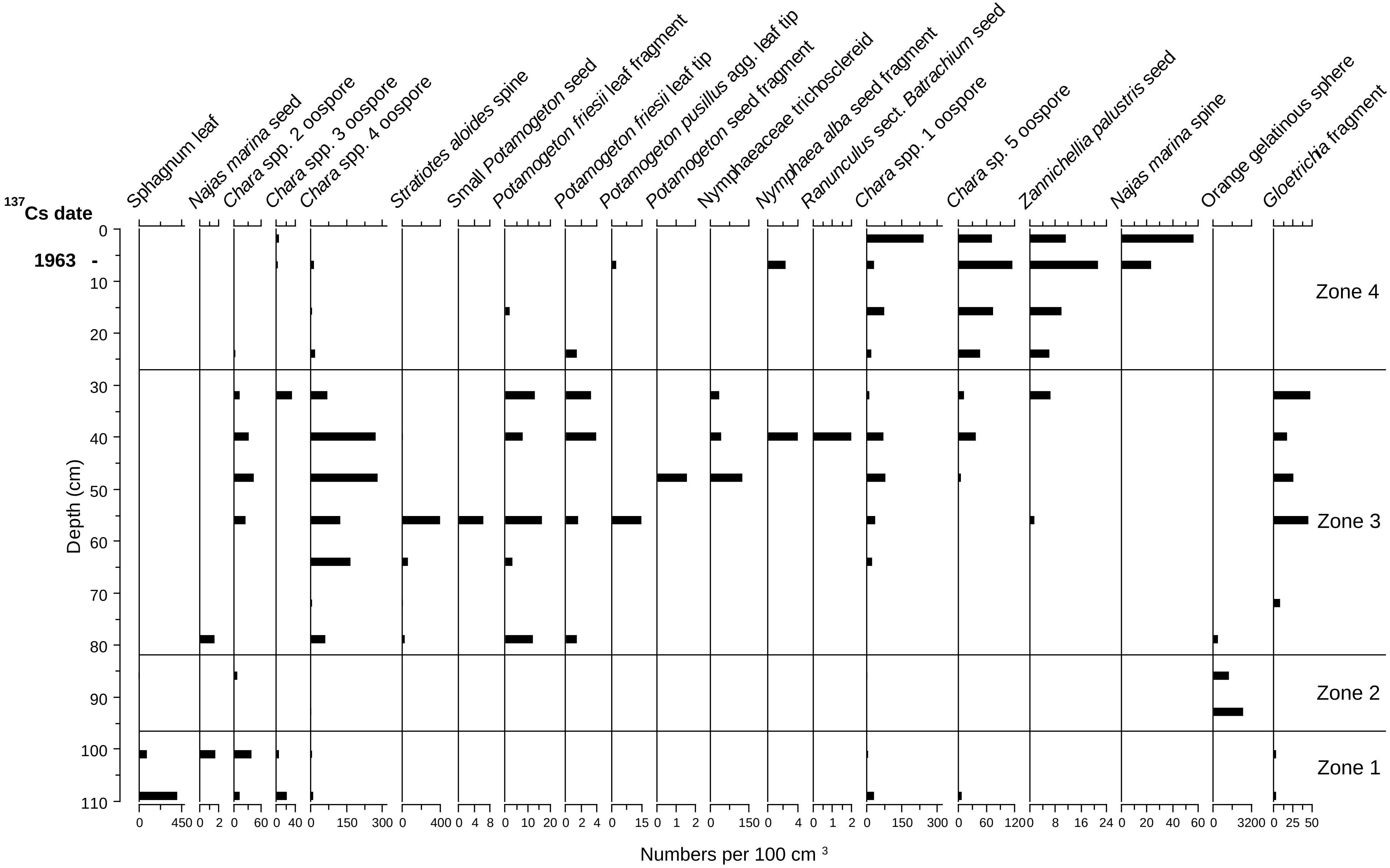


Figure 11. Summary stratigraphy of mollusc and cladoceran remains for UPTL1 from Upton Little Broad

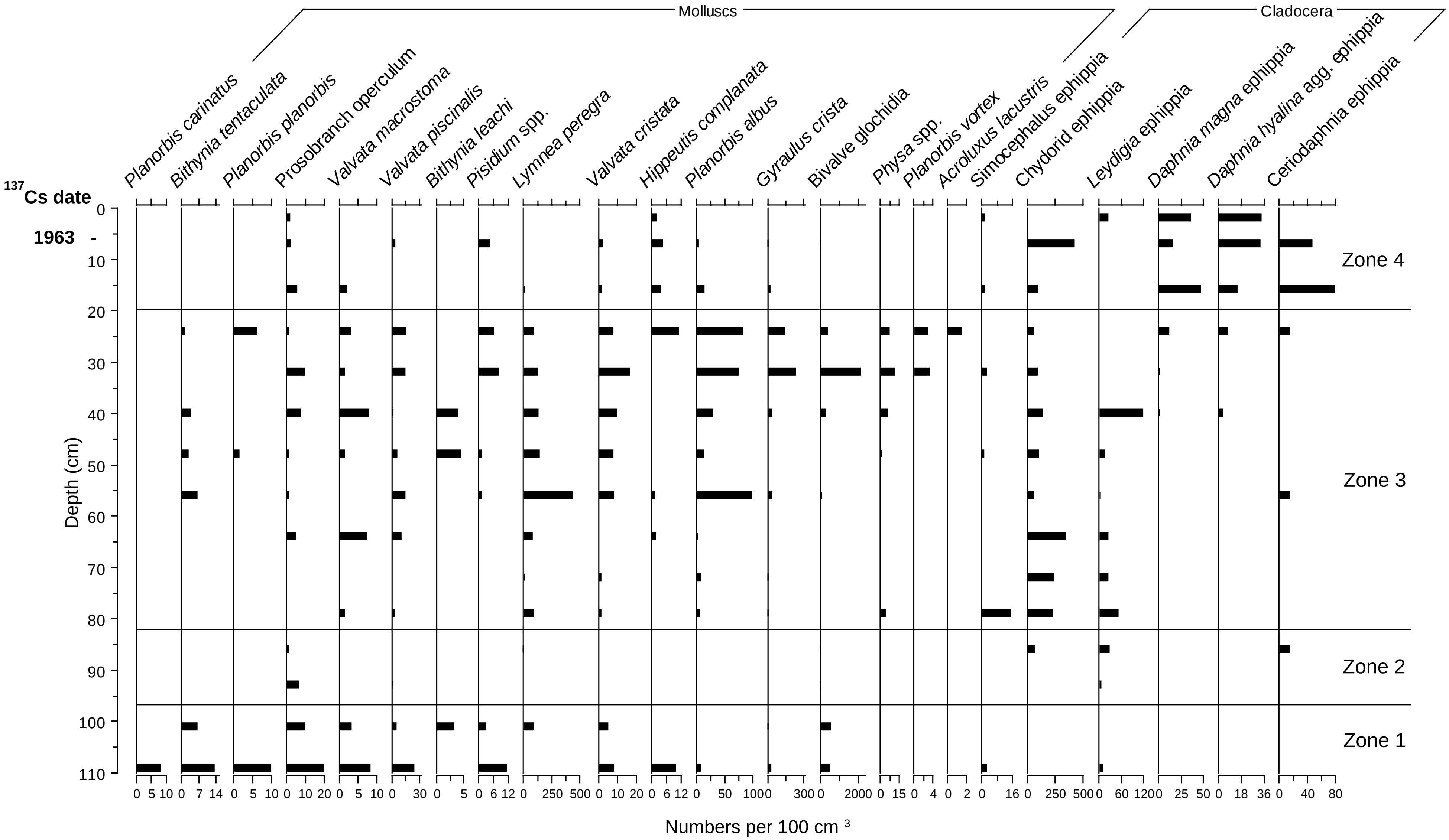
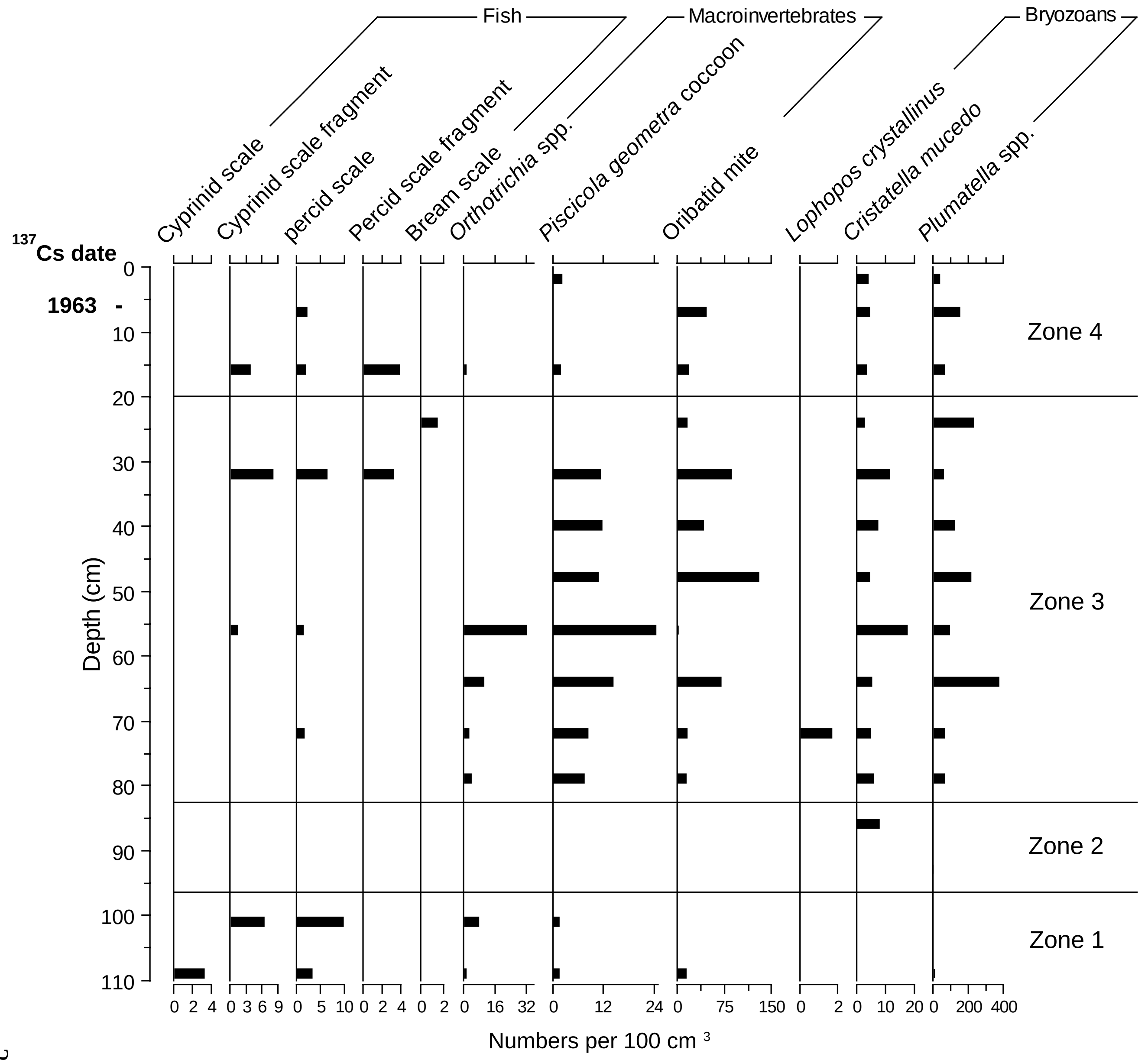


Figure 12. Summary stratigraphy of fish, macroinvertebrates and bryozoans for UPTL1 from Upton Little Broad



Interpretation of results

The adaptations of the standard macrofossil methods applied here, i.e. the use of two sieve sizes and maximising the volume of sediment analysed from the larger fraction, appear to have produced reliable data. The number and diversity of, in particular, plant remains compares favourably with both published data (e.g. Odgaard & Rasmussen 2001; Davidson *et al*. 2005) and with other palaeolimnological studies of similar sites (e.g. Davidson & Appleby 2003). A number of studies have demonstrated that the analysis of plant macrofossils in sediments is unlikely to reconstruct past species diversity as rare species and those which leave fewer remains (e.g. *Potamogeton* species) are likely to be under-represented (Davis 1985; Dieffenbacher-Krall & Halteman 2000). The m method has, however, been shown to provide a reliable means with which to track changes in the dominant components of the submerged vegetation of shallow lakes (Davidson *et al*. 2005).

In addition to sub-fossils of aquatic vegetation, those left by animals, such as fish, molluscs and cladocerans can shed light on past changes in the ecological structure and function of shallow lakes (Jeppesen *et al* 2001). Cocoons of the fish leech *P. geometra* may provide information on plant abundance as they require not only fish, on which they feed, but also plant surfaces to which the cocoons are attached (Odgaard & Rasmussen 2001). Thus, in addition to the direct information provided by the remains of the actual plants these animal remains provide complementary information on both plant abundance and wider changes in ecological functioning.

The results presented here strongly suggest that all three Broads have undergone significant changes in their aquatic vegetation, and their associated biota, over the life of the Broads. Although actual change in species composition has varied between sites all have seen a decline and/or loss of those species associated with lower nutrient concentrations.

Whilst this study has been able to highlight the shifts in macrophyte community structure that have occurred over time the changes in ecological function responsible for and resulting from these alterations have not been elucidated. These aspects could be investigated by analysing the sub-fossil remains of other biological groups within the sediment cores. For example, analysis of cladoceran remains can provide insights into changes in plant abundance and in the changes in the structure of the fish population, in particular variation in zooplanktivorous fish predation pressure (Jeppesen *et al*. 2001). Such analysis may provide information on the causes of any shifts in the aquatic flora which may feed into the development of management strategies.

Little Broad

An accumulation rate of 1 mm y^{-1} post 1963 as suggested by the ^{137}Cs profile is very low for a nutrient enriched shallow lake. There may, however, have been a slowing of accumulation as the water depth reduced over the last few decades. Within lake production of sedimentary material may have fallen as planktonic productivity is likely to have diminished as the water column became smaller. The overall result of these processes may have lowered the sediment accumulation rate. This likely variation in accumulation rate, combined with the lack of a reliable ^{210}Pb profile, made the calculation of a reliable chronology difficult for LILT1.

The macrofossil profile indicated a number of shifts in the major components of the submerged flora over the time period represented by the core. The ancestral community was dominated by *Chara* and contained at least three species of *Potamogeton*, (*P. pusillus* type, *P. obtusifolius* and *P. friesii*), with less abundant *Ceratophyllum* spp. and *Nitella*. In zone 1 it is likely there was a shift from *Chara* to *Ceratophyllum*, however, the numbers of *Chara* oospores (>1000 per 100 cm^3), suggest there were still extensive *Chara* beds (Zhao *et al*. 2006). In zone 2 the data suggest that a community of *Chara*/*Potamogeton*/*Ceratophyllum* gave way to a different flora dominated by

Nitella and *S. aloides*. The final shift in this zone reflects a further change in community structure as *N. alba* and *Z. palustris* became more important components of the assemblage. The shifts in flora are in keeping with those to be expected from the progressive eutrophication of the site (Sand-Jensen 1997, Körner 2000, Egertson *et al*. 2004) as those species associated with lower nutrient levels were lost from the site and were replaced by species normally found at higher nutrient concentrations.

The final change which occurred in zone 3 suggests that the site ceased to support a viable macrophyte community. The cause of which is difficult to attribute to one factor alone, as the lake became too shallow to support submerged species and nutrient levels increased at the same time. It is likely the loss of sufficient water depth was the direct cause of the loss of plants but in turn the accelerated sedimentation rates were the result of eutrophication.

The animal macrofossil profile, in particular the trichopteran and mollusc data, support the idea of a changed plant community. These animals may have responded to either the different plant architecture after the decline of *Chara* in zone 1, or perhaps to changes in the ecological function associated with enrichment. Within zone 2, in particular towards the top, a range of animal fossils (e.g. undifferentiated trichopteran, *Orthotrichia* spp. and *Bythinia* spp.) indicated a gradual decline in either plant abundance or an increase relative abundance of a less preferable plant species. It is difficult to state with certainty that there was a decline in plant abundance. What is true is that plant-associated species declined and it may be that that submerged species coverage also fell. The fish leech *P. geometra* requires a host fish, its cocoons, however, require plant surface for attachment. The reduction in numbers may suggest that that submerged species abundance diminished from the middle of zone 2 upwards (Odgaard & Rasmussen 2001).

Cromes Broad

The very low ^{210}Pb activity unfortunately made establishing a good chronology for CROM1 The poor definition of ^{137}Cs may be due to disturbance and reworking of old sediments as a result of the dredging operation carried out at the site. Unfortunately, as for LILT1 it was not possible to establish a chronology for CROM1.

The Cromes Broad plant macrofossil profile had a very high diversity of identifiable remains. The Broad appears to have gone through a series of changes in its submerged flora. The data suggest a relatively unusual flora for the Broads dominated by a combination of *Nitella* spp. and *Chara* spp. 1, but with the addition of *Myriophyllum alterniflorum*. *M. alterniflorum* is currently uncommon in the region and in the past may well have been limited to lower alkalinity sites. There is a suggestion that the community structure shifted within zone 1 as *Nitella* abundance declined, *M. alterniflorum* disappeared and *Chara* species composition shifted from *Chara* spp. 5 to *Chara* spp. 3. In addition *Chara*, *Nitella* and *M. alterniflorum* there were an array of *Potamogeton* species present at this time, including *P. obtusifolius* and *P. praelongus* (currently a rare species in lowland England and the Broads) and also *Ranunculus* sect. *Batrachium*. The presence of low numbers of *Z. palustris* seeds at this time does not necessarily mean that it was abundant at the site as this species is a prolific seed producer (Zhao *et al*. 2006).

This ancestral charophyte, pondweed community was lost at the transition between zones 1 and 2 as species more associated with elevated nutrient levels, *N. alba* and *Ceratophyllum* spp became dominant. The fact that a seed of *C. demersum* was present in the record suggests that the leaf spines came from this species rather than the rarer *Ceratophyllum submersum*. Towards the top of zone 2 *S aloides* may have become more abundant as *C. demersum* declined. The final shift in zone 3 suggests there was low species diversity and reduced coverage of submerged plants, with perhaps sparse coverage of *C. demersum*, *N. alba* and the presence of *Lemna* spp., consistent with the current flora of the site.

The remains of plant associated animals, such as *P. geometra*, *Plumatella* spp and all the trichopteran species, indicate that plant abundance may have increased in zone 2. *C. demersum* in particular can grow prolifically in slightly enriched sites and it may have had a relatively high coverage during this period. The disappearance of the ephippia of *D. pulex*, the most plant associated *Daphnia* species, and increases in the other planktonic cladocerans, *Ceriodaphnia* and *D. hyalina* agg., suggest that plant abundance may have declined.

Upton Little Broad

Despite higher ^{210}Pb levels in the uppermost sediments it was still not possible to establish a longer term chronology for UPTL1. Again the ^{137}Cs provided one date for the core and suggest a relatively low accumulation rate for the site in the last few decades. It is likely, however, that there has been some acceleration in the rate of sediment accumulation.

The remains from Upton Little Broad were diverse, with rich plant and, in particular, mollusc assemblages. In keeping with the other sites in this study Upton Little Broad has gone through a series of changes in ecological structure, but in contrast to the other sites it still has an extant submerged plant community. The lowest sediment sample analysed was on the cusp between the basal peat and true lake sediment. The Broad initially contained five species of *Chara*, *N. marina* along with a diverse mollusc assemblage, an apparently healthy fish community containing percid and cyprinid species and a number of plant-associated macroinvertebrates. Zone 2 was unusual in that there was an almost complete absence of remains of truly aquatic species. The samples were dominated by an unidentified orange gelatinous material which may have been the remains of some form of colonial algae. It is difficult to interpret this dramatic shift in assemblage which may represent up to 150-200 years. An extreme reduction in water level could produce such a response, if water depth fell below a level capable of supporting submerged vegetation. Some cladocerans were present in zone 2, these were generally benthic species and their presence means water was present but may indicate that it was relatively shallow.

The initial paucity of remains in zone 3 may reflect the Broad's recovery from the alteration in community structure in zone 2, the remains of plants and molluscs were relatively sparse. The increase in abundance of remains towards the centre of the zone suggests the flora consisted of *Chara*, *P. friesii* and *S. aloides*. Towards the top of zone 3 there was probably a shift in the community to include a greater proportion of *N. alba*, *R.* sect. and *Batrachium* and *Chara* spp. 2 and 4. The data indicate the subsequent loss and/or decline of *Chara* species 2, 3 and 4 in zone 4. There was also a parallel rise in dominance of *Chara* species 1 and 5 at this time and *Z. palustris* and *N. marina* became more important components of the community. This last group reflects the extant community relatively accurately. The shift in mollusc abundance and in cladoceran species composition may reflect a decline in plant coverage over the last few decades. The increase in planktonic cladocerans indicates an increase in the pelagic proportion of primary productivity, a change in ecological function associated with nutrient enrichment (Vadeboncoeur *et al*. 2003).

Recommendations

Little Broad

Having completely lost its submerged flora and being extremely shallow the site has little value when considered as a body of open water. The removal of the lake's sediments could restore some depth to the site, and remove one of the potential sources of nutrients. If dredging or suction pumping of the Broad's sediments were undertaken it would be vital to remove the sediment to a sufficient depth to allow the original community to establish itself and also to ensure that more phosphorus rich sediments are removed. The general colour changes in the core corresponded well to the macrofossil stratigraphy and this suggests it would be desirable to remove around 80 cm of sediment if the aim were to restore the original *Chara* dominated community. If this were done it would be vital to assess the current sources of enrichment for the Broad. Dredging without reducing the nutrient inputs may well preclude the establishment of the ancestral submerged flora.

The soft nature of the basal peat layer of the sediments precluded the accurate measurement of sediment depth during the site survey. Thus, calculating the volume of sediment to be removed from the site has to be based on the assumption of uniform sediment depth. Whilst this assumption is unlikely to be true, in shallow lakes with a uniform basin such as Little Broad, calculations based on the assumption are still valuable. If 80 cm of sediment was removed from the entire basin the total volume of sediment would be approximately 8,300 m^3.

Cromes Broad

Cromes Broad has recently been dredged. The work here suggests that compared to the more base rich Bure and Yare systems, the Ant, and perhaps Cromes in particular, had a relatively distinct flora in the region with *Myriophyllum alterniflorum* and *P. praelongus* present. This information on the former plant community provides a yard-stick against which to measure the success of restoration work.

A number of studies have demonstrated the effects of nutrient enrichment on submerged macrophytes (Jupp & Spence 1977, Blindow 1992; Jeppesen 1998, James *et al*. 2005). The effects of progressive nutrient enrichment on a shallow lake were clearly demonstrated by the macrofossil profile from Cromes Broad as the plant communities underwent complete turnover in species assemblage. It is, therefore, vital that, in combination with the removal of mud from the lake bed, the sources of nutrients that led to the decline in ecological quality are ameliorated. In addition, at Cromes Broad it may be necessary to assess the potential of the sediments in the lake margins, which were not removed in the dredging operation, as a source of phosphorus release.

Upton Little Broad

As at the other sites Upton Little Broad has clearly undergone massive changes in its macrophyte flora as a result of eutrophication. Unlike the other sites Upton Little Broad supports a relatively extensive population of *Najas marina* an extremely rare species of submerged plant which is protected under schedule 8 of the Wildlife and Countryside Act, 1981, and is listed as vulnerable in the British Red Data book and in the IUCN European Red Data Categories. Thus, sediment removal at the site to re-instate water depth needs to be agreed by all parties and supported by defined objectives, rigorous assessment of data and sensitive delivery. Any action at a site containing a viable community of such a rare plant needs to be very carefully considered as the Upton Broad system forms the U.K. stronghold of *N. marina*. If sediment were to be removed from Upton Little Broad one of the key questions that must be addressed is what is the target community? If the site were to be dredged what depth of sediment should be removed? The removal of sediment may not accord well with the aim of maintaining *N. marina*. Removal of the lake’s mud will reveal the more compacted sediments beneath and *N marina* has been shown to have a preference for sediments of low cohesion strength (Handley & Davy 2000). Thus, the current flocculent sediments may be the factor leading to the healthy population of *N. marina*.

If the target community was the *Chara* rich historical assemblage of the Broad then approximately 100 cm of sediment should be removed. The Broad did contain *N. marina* at that time but its re-establishment could not be guaranteed as the seeds from that depth may not be viable and the sediments may be too firm for it to establish. Thus, the development of a coherent management strategy with clear targets is vital.

The philosophy of dredging and future work

The removal of sediment from a lake is a costly and extreme course of action (Moss *et al*. 1996b). The disposal of the sediment has to be carefully considered and carried out with care. As mentioned above it is also un-sustainable to dredge a site without considering the present day nutrient load. If nutrients load is undiminished the symptoms, but not the cause, of eutrophication will have been treated and changes in plant community and accelerated in-filling of the lake will occur once again.

It would be interesting to consider some of the alternatives to dredging to solving the environmental problems of shallow lakes. One such idea is that some of the sites should be allowed to follow their natural, albeit accelerated, trajectory and ultimately fill in to form wetlands. Combined with this new lakes could be dug to compensate for the loss of freshwater habitat. The in-filling of these sites will create relatively unique environments, which whilst they have little value when thought of as lakes provide habitat for a whole host of flora and fauna. Not only do such sites provide habitat but they may also benefit ecological health on a larger landscape scale through their functioning for example the removal of nitrogen from water courses through de-nitrification (Moss 1998). Furthermore, whilst an enriched lake's sediments are a source of nutrients to the overlying water, an in-filled site's sediments may function as a nutrient sink and sediment trap when considered on a wider catchment scale.

Another management issue to consider is the effect of the partial removal of lake sediment, as has occurred at Cromes Broad. The sediment has not been removed from all areas the lake edge has been left relatively undisturbed resulting in a shallow marginal zone. The Broads are unique aquatic systems for a number of reason, the relatively steeply shelving margins of the water-bodies, a result of their origins as peat diggings, being one of the distinctive features. There may be implications of the partial removal of sediment that leads to shallow lake margins. For example how significant a nutrient source is the remaining sediment? There may be other ecological implications e.g. several species of macrophyte, perhaps more shade tolerant species such as the aquatic mosses (e.g. *Fontinalis antipyretica*), tend to occupy the lake edge but also prefer water with significant depth (i.e. > 50 cm). Broadland species currently limited to dyke systems, for example, *Potamogeton acutifolius*, *Potamogeton coloratus* and *Myriophyllum verticillatum* may well prefer the relatively deep water at the lake edge. These species may on the other hand be limited simply by nutrient levels; but other confounding factors to the restoration of ecological quality need to be considered and research into habitat preferences of different species may elucidate the most appropriate management techniques.

A further area of research highlighted by this study is looking into the viability of the seeds buried within the lake sediments. For example, are the seeds of *Najas marina* at a depth of 80 cm in Upton Little Broad viable? How long do *Chara* oospores retain the ability to germinate? Can we, not only restore lakes their previous condition but, by using the ancestral seed bank, also retain the same genetic lineage of plants at that site?

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Appendices

All data are expressed as numbers 100 per cm^3 of wet sediment

Appendix 1

sample	depth (cm)	Pike scale	Perchid scale	Percid frag	Cyprinid scale	Cyprinid frag	Unid scale frag	Fish vertebrae
LILT1	1-3	0	0	0	0	0	0	0
LILT1	7-9	0	0	0	0	1.639344262	1.639344262	0
LILT1	13-15	0	0	3.225806452	1.612903226	0	8.064516129	0
LILT1	19-21	0	0	0	0	0	0	0
LILT1	25-27	0	0	0	0	0	0	0
LILT1	31-33	0	0	0	0	0	1.666666667	0
LILT1	37-39	0	0	3.333333333	0	0	0	0
LILT1	43-45	0	1.666666667	1.666666667	0	0	0	0
LILT1	49-51	0	0	0	0	1.639344262	0	0
LILT1	55-57	1.666666667	0	1.666666667	0	3.333333333	0	0
LILT1	61-63	0	1.612903226	3.225806452	0	1.612903226	3.225806452	0
LILT1	67-69	0	0	1.587301587	0	0	1.587301587	0
LILT1	76-78	0	0	1.851851852	0	1.851851852	3.703703704	1.85
LILT1	85-87	1.666666667	0	0	8.333333333	0	0	0
LILT1	94-96	0	0	1.666666667	0	5	3.333333333	0

sample	depth (cm)	Fronto clypeus	Orthotrichia	P. geometra (coccoons)	Corixidae elytra fragments	Coleoptera frag	undif Trichoptera case	Daphnia spp.
LILT1	1-3	21.31147541	0	6.557377049	8.196721311	0	0	103.2786885
LILT1	7-9	4.918032787	0	4.918032787	11.47540984	1.639344262	0	119.6721311
LILT1	13-15	1.612903226	3.225806452	4.838709677	6.451612903	0	0	8.064516129
LILT1	19-21	0	0	6.557377049	0	6.557377049	0	3.278688525
LILT1	25-27	4.918032787	0	3.278688525	0	0	0	1.639344262
LILT1	31-33	1.666666667	1.666666667	5	3.333333333	0	0	1.666666667
LILT1	37-39	0	1.666666667	8.333333333	3.333333333	1.666666667	0	35
LILT1	43-45	26.66666667	0	3.333333333	3.333333333	3.333333333	0	0
LILT1	49-51	27.86885246	8.196721311	11.47540984	1.639344262	4.918032787	0	0
LILT1	55-57	11.66666667	8.333333333	11.66666667	3.333333333	5	0	1.666666667
LILT1	61-63	6.451612903	11.29032258	8.064516129	0	4.838709677	1.612903226	1.612903226
LILT1	67-69	34.92063492	14.28571429	17.46031746	1.587301587	1.587301587	3.174603175	0
LILT1	76-78	27.77777778	9.259259259	16.66666667	0	1.851851852	33.33333333	1.851851852
LILT1	85-87	3.333333333	11.66666667	13.33333333	0	1.666666667	123.3333333	0
LILT1	94-96	5	11.66666667	13.33333333	0	1.666666667	45	0

sample	depth (cm)	Simocephalus spp.	Ceriodaphnia spp.	Daphnia magna	Leydigia	C. mucedo	Plumatella spp	L. crystallinus
LILT1	1-3	3.278688525	1.639344262	60.6557377	345.9016393	8.196721311	0	0
LILT1	7-9	3.278688525	0	1.639344262	431.147541	9.836065574	0	0
LILT1	13-15	3.225806452	0	4.838709677	166.1290323	6.451612903	88.70967742	0
LILT1	19-21	0	0	0	55.73770492	3.278688525	24.59016393	0
LILT1	25-27	0	0	3.278688525	80.32786885	4.918032787	8.196721311	0
LILT1	31-33	3.3	0	6.666666667	80	5	0	3.333333333
LILT1	37-39	0	0	1.666666667	203.3333333	6.666666667	8.333333333	0
LILT1	43-45	3.333333333	0	6.666666667	106.6666667	8.333333333	0	0
LILT1	49-51	0	32.78688525	1.639344262	77.04918033	18.03278689	0	1.639344262
LILT1	55-57	3.333333333	0	5	70	13.33333333	0	0
LILT1	61-63	0	0	0	53.22580645	35.48387097	0	1.612903226
LILT1	67-69	3.174603175	0	0	100	26.98412698	47.61904762	1.587301587
LILT1	76-78	1.851851852	18.51851852	1.851851852	31.48148148	38.88888889	27.77777778	0
LILT1	85-87	1.666666667	0	0	1.666666667	21.66666667	8.333333333	0
LILT1	94-96	1.666666667	0	0	0	33.33333333	133.3333333	0

sample	depth (cm)	B. tentac operc	Pisidium spp.	Bivalve glochidia	Chara spp. oospores	Z. palustris	Juncus spp.	Typha spp.
LILT1	1-3	3.278688525	11.47540984	0	34.42622951	0	50.81967213	70.49180328
LILT1	7-9	1.639344262	1.639344262	32.78688525	63.93442623	1.639344262	50.81967213	9.836065574
LILT1	13-15	0	3.225806452	0	25.80645161	0	114.516129	67.74193548
LILT1	19-21	1.639344262	0	0	19.67213115	0	32.78688525	21.31147541
LILT1	25-27	0	0	0	27.86885246	0	65.57377049	0
LILT1	31-33	1.666666667	1.666666667	0	85	0	50	16.66666667
LILT1	37-39	1.666666667	5	0	28.33333333	3.333333333	535	1.666666667
LILT1	43-45	3.333333333	0	0	70	0	216.6666667	3.333333333
LILT1	49-51	0	1.639344262	0	70.49180328	0	229.5081967	1.639344262
LILT1	55-57	3.333333333	0	0	33.33333333	1.666666667	266.6666667	16.66666667
LILT1	61-63	1.612903226	0	0	45.16129032	1.612903226	274.1935484	16.12903226
LILT1	67-69	12.6984127	0	0	182.5396825	0	609.5238095	1.587301587
LILT1	76-78	96.2962963	0	0	1320.37037	0	129.6296296	0
LILT1	85-87	116.6666667	0	0	1203.333333	0	66.66666667	0
LILT1	94-96	146.6666667	0	0	2938.333333	0	166.6666667	18.33333333

Appendix 2

core	Depth	A. plantago-aquatica	Alnus	Apium spp.	Arcella	Birch	B. umbellatus	Callitriche	Carex sp_
CROM1	1-3	0	0	0	0	6.666666667	0	0	0
CROM1	10-12	0	0	0	145.4545455	3.636363636	0	0	7.272727273
CROM1	19-21	0	0	0	480	0	0	2	0
CROM1	37-39	0	0	0	290.3225806	0	0	16.12903226	0
CROM1	55-57	0	0	0	1385.964912	0	0	0	0
CROM1	64-66	0	0	1.666666667	3166.666667	0	0	0	6.666666667
CROM1	75-77	0	0	0	576.5625	1.5625	0	1.5625	0
CROM1	82-84	0	0	0	2933.333333	0	0	0	1.666666667
CROM1	91-93	0	0	0	366.6666667	0	0	1.666666667	5
CROM1	100-102	3.333333333	0	0	250	0	0	1.666666667	3.333333333
CROM1	118-120	0	0	0	0	3.333333333	1.666666667	1.666666667	16.66666667
CROM1	127-129	0	1.666666667	0	216.6666667	21.66666667	0	53.33333333	11.66666667

core	Depth	Centropyxis	C. demersum seed	C. demersum spine	Ceriodaphnia	Chara spp_1	Chara spp_3	Chara spp_5	Chydorid
CROM1	1-3	0	0	44.44444444	182.2222222	0	0	0	177.7777778
CROM1	10-12	0	0	40	45.45454545	5.454545455	0	0	201.8181818
CROM1	19-21	260	0	136	120	4	0	0	220
CROM1	37-39	145.1612903	1.612903226	433.8709677	435.483871	4.838709677	0	0	193.5483871
CROM1	55-57	52.63157895	0	443.8596491	105.2631579	7.01754386	0	0	245.6140351
CROM1	64-66	66.66666667	0	633.3333333	83.33333333	8.333333333	0	0	133.3333333
CROM1	75-77	62.5	0	1451.5625	15.625	32.8125	0	0	0
CROM1	82-84	383.3333333	0	330	25	201.6666667	8.333333333	0	33.33333333
CROM1	91-93	0	0	30	8.333333333	141.6666667	3.333333333	0	33.33333333
CROM1	100-102	0	0	5	33.33333333	266.6666667	20	0	0
CROM1	118-120	0	0	0	25	316.6666667	0	3.333333333	1.666666667
CROM1	127-129	0	0	0	16.66666667	101.6666667	0	0	33.33333333

core	Depth	C. mucedo	Cyprinidae frag	Cyprinidae scale	D. hyalina agg.	Daphnia pulex ephippia	Difflugia	Epilobium palustre	E. cannabinum
CROM1	1-3	2.222222222	0	0	135.5555556	0	200	0	0
CROM1	10-12	5.454545455	0	1.818181818	7.272727273	0	963.6363636	0	0
CROM1	19-21	6	0	0	4	0	160	0	0
CROM1	37-39	3.225806452	3.225806452	0	27.41935484	0	532.2580645	0	0
CROM1	55-57	38.59649123	0	0	7.01754386	3.50877193	175.4385965	0	0
CROM1	64-66	13.33333333	0	0	20	1.666666667	366.6666667	0	0
CROM1	75-77	42.1875	0	0	0	3.125	31.25	0	0
CROM1	82-84	96.66666667	0	0	11.66666667	1.666666667	1650	0	0
CROM1	91-93	75	0	0	11.66666667	0	16.66666667	0	1.666666667
CROM1	100-102	33.33333333	0	0	1.666666667	0	383.3333333	1.666666667	0
CROM1	118-120	43.33333333	0	0	3.333333333	0	733.3333333	0	0
CROM1	127-129	18.33333333	0	0	1.666666667	1.666666667	0	1.666666667	0

core	Depth	Gleochidium	Gleotrichia	Golden Moss	Hydrocotyle vulgaris	Hypericum elodes	Juncus	Lemna	Leydigia ephippia
CROM1	1-3	111.1111111	11.11111111	11.11111111	0	0	2.222222222	2.222222222	113.3333333
CROM1	10-12	54.54545455	78.18181818	0	0	0	90.90909091	0	120
CROM1	19-21	0	108	0	0	0	40	0	102
CROM1	37-39	0	177.4193548	0	0	0	66.12903226	0	58.06451613
CROM1	55-57	0	1026.315789	0	0	0	175.4385965	0	21.05263158
CROM1	64-66	0	908.3333333	83.33333333	1.666666667	1.666666667	100	0	6.666666667
CROM1	75-77	0	879.6875	45.3125	0	0	109.375	0	17.1875
CROM1	82-84	0	585	73.33333333	0	0	233.3333333	0	1.666666667
CROM1	91-93	0	1010	85	1.666666667	1.666666667	550	0	0
CROM1	100-102	0	660	561.6666667	1.666666667	1.666666667	1950	0	0
CROM1	118-120	0	535	400	0	3.333333333	3000	0	0
CROM1	127-129	0	320	480	0	0	5000	0	0

core	Depth	L. cristallinus	M. alterniflorum	Nitella	Nymphaea alba	Nymphaea alba seed fragment	Oribatei	Orthotrichia	Oxyethira
CROM1	1-3	2.222222222	0	0	0	2.222222222	66.66666667	0	0
CROM1	10-12	0	0	0	0	3.636363636	76.36363636	0	0
CROM1	19-21	2	0	0	0	8	24	4	0
CROM1	37-39	0	0	0	0	6.451612903	119.3548387	8.064516129	0
CROM1	55-57	0	0	0	1.754385965	7.01754386	126.3157895	12.28070175	1.754385965
CROM1	64-66	0	0	1.666666667	3.333333333	10	186.6666667	1.666666667	0
CROM1	75-77	0	0	0	4.6875	3.125	15.625	4.6875	0
CROM1	82-84	0	0	0	1.666666667	3.333333333	233.3333333	40	0
CROM1	91-93	0	0	6.666666667	0	0	183.3333333	11.66666667	0
CROM1	100-102	0	0	53.33333333	0	0	188.3333333	8.333333333	0
CROM1	118-120	0	1.666666667	308.3333333	0	0	186.6666667	11.66666667	0
CROM1	127-129	1.666666667	0	160	0	0	176.6666667	5	0

core	Depth	Percid scale	P. geometra	Pisidium	Plumatella spp	P. friesii seed	P. friesii leaf frag	P. friesii leaf tip	Potamogeton leaf
CROM1	1-3	0	0	2.222222222	180	0		0	0
CROM1	10-12	1.818181818	18.18181818	0	312.7272727	0	0	0	0
CROM1	19-21	0	22	0	360	0	0	0	0
CROM1	37-39	0	24.19354839	0	306.4516129	0	0	0	1.612903226
CROM1	55-57	0	52.63157895	0	666.6666667	0	1.754385965	0	0
CROM1	64-66	0	15	0	416.6666667	0	6.666666667	0	3.333333333
CROM1	75-77	0	10.9375	0	440.625	0	3.125	1.5625	0
CROM1	82-84	0	36.66666667	0	491.6666667	6.666666667	10	0	0
CROM1	91-93	0	25	0	183.3333333	3.333333333	18.33333333	20	0
CROM1	100-102	0	16.66666667	0	133.3333333	3.333333333	30	11.66666667	0
CROM1	118-120	0	1.666666667	0	50	0	0	0	0
CROM1	127-129	0	1.666666667	0	58.33333333	0	28.33333333	16.66666667	0

core	Depth	P. obtusifolius leaf tip	P. praelongus seed	P. praelongus leaf	P. pusillus leaf frag	P. pusillus leaf tip	P. pusillus seed	Pot seed
CROM1	1-3	0	0	0	0	0	0	0
CROM1	10-12	0	0	0	0	0	0	0
CROM1	19-21	2	0	0	0	0	0	0
CROM1	37-39	0	0	0	0	0	0	0
CROM1	55-57	1.754385965	0	0	3.50877193	10.52631579	0	0
CROM1	64-66	1.666666667	0	0	0	3.333333333	0	0
CROM1	75-77	0	0	0	0	4.6875	0	0
CROM1	82-84	3.333333333	6.666666667	265	0	8.333333333	0	1.666666667
CROM1	91-93	3.333333333	5	40	5	31.66666667	0	10
CROM1	100-102	1.666667	0	13.33333333	11.66666667	13.33333333	1.666666667	1.666666667
CROM1	118-120	3.333333333	0	0	8.333333333	0	0	5
CROM1	127-129	21.66666667	0	13.33333333	15	35	0	3.333333333

core	Depth	Pot seed frag	Pot seed lid	Prosobranch operc	Ranunculus	Ranunculus frag	Ranunculus repens	Rotifer egg	Rumex
CROM1	1-3	0	0	0	0	0	0	22.22222222	0
CROM1	10-12	0	0	1.818181818	0	0	0	109.0909091	0
CROM1	19-21	0	0	0	0	0	0	120	0
CROM1	37-39	1.612903226	0	0	0	0	0	80.64516129	0
CROM1	55-57	0	0	0	0	0	0	157.8947368	0
CROM1	64-66	1.666666667	0	0	0	1.666666667	0	50	0
CROM1	75-77	0	0	0	0	0	0	0	0
CROM1	82-84	0	0	0	0	0	0	50	0
CROM1	91-93	0	3.333333333	0	1.666666667	0	0	16.66666667	0
CROM1	100-102	0	0	0	6.666666667	0	0	0	1.666666667
CROM1	118-120	0	0	0	0	0	1.666666667	0	0
CROM1	127-129	0	1.666666667	0	1.666666667	0	0	0	0

core	Depth	Sagittaria sagittifolia	scalloped egg	Scheonoplectus	Simocephalus	Sphagnum leaf	Sponge balls	Stratiotes aloides	Trichoptera a
CROM1	1-3	0	177.7777778	0	13.33333333	55.55555556	26.66666667	0	0
CROM1	10-12	1.818181818	18.18181818	0	1.818181818	176.3636364	7.272727273	25.45454545	0
CROM1	19-21	0	20	0	14	448	64	164	0
CROM1	37-39	0	16.12903226	0	9.677419355	525.8064516	14.51612903	187.0967742	0
CROM1	55-57	0	17.54385965	1.754385965	5.263157895	1984.210526	135.0877193	157.8947368	3.50877193
CROM1	64-66	0	16.66666667	0	1.666666667	971.6666667	36.66666667	23.33333333	1.666666667
CROM1	75-77	0	15.625	0	0	123.4375	31.25	0	6.25
CROM1	82-84	0	0	0	0	48.33333333	823.3333333	0	0
CROM1	91-93	0	0	0	0	23.33333333	833.3333333	0	0
CROM1	100-102	0	16.66666667	1.666666667	0	3.333333333	350	0	0
CROM1	118-120	0	0	0	21.66666667	33.33333333	5	0	0
CROM1	127-129	0	500	0	0	25	65	0	1.666666667

core	Depth	Trichoschleroid	Typha	Zannichellia palustris seed
CROM1	1-3	0	4.444444444	0
CROM1	10-12	0	3.636363636	0
CROM1	19-21	0	8	0
CROM1	37-39	32.25806452	6.451612903	0
CROM1	55-57	52.63157895	57.89473684	0
CROM1	64-66	200	8.333333333	0
CROM1	75-77	109.375	4.6875	0
CROM1	82-84	116.6666667	1.666666667	0
CROM1	91-93	0	1.666666667	0
CROM1	100-102	0	0	1.666666667
CROM1	118-120	0	0	0
CROM1	127-129	0	0	0

Appendix 3

SampleName	Depth	Bream scale	A. lacustris	Arcella	Birch	B. leachi	B. tentaculata	C. rectirostris
UPTL1	1-3	0	0	0	0	0	0	0
UPTL1	8-10	0	0	404.7619048	2.380952381	0	0	0
UPTL1	15-17	0	0	220	6	0	0	0
UPTL1	23-25	1.587301587	1.587301587	396.8253968	0	0	1.587301587	0
UPTL1	31-33	0	0	183.3333333	0	0	0	0
UPTL1	39-41	0	0	360	0	4	4	0
UPTL1	47-49	0	0	328.125	0	4.6875	3.125	0
UPTL1	55-57	0	0	196.7213115	0	0	6.557377049	0
UPTL1	63-65	0	0	1818.181818	0	0	0	18.18181818
UPTL1	71-73	0	0	68.96551724	0	0	0	1.724137931
UPTL1	78-80	0	0	138.4615385	0	0	0	15.38461538
UPTL1	85-87	0	0	0	0	0	0	0
UPTL1	92-94	0	0	0	0	0	0	0
UPTL1	100-102	0	0	0	0	3.333333333	6.666666667	0
UPTL1	108-110	0	0	0	0	0	13.33333333	0

SampleName	Depth	Ceriodaphnia	Chara spp_1	Chara spp_2	Chara spp_3	Chara spp_4	Chara spp_5	Chydorid
UPTL1	1-3	0	243.1818182	0	6.818181818	0	72.72727273	0
UPTL1	8-10	47.61904762	33.33333333	0	4.761904762	16.66666667	116.6666667	428.5714286
UPTL1	15-17	80	78	0	0	8	76	100
UPTL1	23-25	17.46031746	20.63492063	4.761904762	0	22.22222222	47.61904762	63.49206349
UPTL1	31-33	0	11.66666667	13.33333333	33.33333333	71.66666667	13.33333333	100
UPTL1	39-41	0	74	34	0	272	38	140
UPTL1	47-49	0	82.8125	45.3125	0	281.25	6.25	109.375
UPTL1	55-57	16.39344262	39.3442623	26.2295082	0	124.5901639	0	65.57377049
UPTL1	63-65	0	27.27272727	1.818181818	0	169.0909091	0	345.4545455
UPTL1	71-73	0	3.448275862	0	0	8.620689655	1.724137931	241.3793103
UPTL1	78-80	0	0	0	0	61.53846154	0	230.7692308
UPTL1	85-87	16.66666667	1.666666667	8.333333333	0	5	0	75
UPTL1	92-94	0	0	0	0	1.666666667	0	0
UPTL1	100-102	0	10	40	6.666666667	8.333333333	0	0
UPTL1	108-110	0	33.33333333	13.33333333	23.33333333	13.33333333	8.333333333	0

SampleName	Depth	C. mucedo	Cyprinidae frag	Cyprinidae scale	D. hyalina agg.	Daphnia magna	E. cannabinum	F. ulmaria
UPTL1	1-3	4.545454545	0	0	34.09090909	36.36363636	0	0
UPTL1	8-10	4.761904762	0	0	33.33333333	16.66666667	2.380952381	0
UPTL1	15-17	4	4	0	16	48	0	0
UPTL1	23-25	3.174603175	0	0	7.936507937	12.6984127	0	0
UPTL1	31-33	11.66666667	8.333333333	0	0	1.666666667	0	0
UPTL1	39-41	8	0	0	4	2	0	0
UPTL1	47-49	4.6875	0	0	0	0	0	0
UPTL1	55-57	18.03278689	1.639344262	0	0	0	0	0
UPTL1	63-65	5.454545455	0	0	0	0	0	0
UPTL1	71-73	5.172413793	0	0	0	0	0	0
UPTL1	78-80	6.153846154	0	0	0	0	0	1.538461538
UPTL1	85-87	8.333333333	0	0	0	0	0	0
UPTL1	92-94	0	0	0	0	0	0	0
UPTL1	100-102	0	6.666666667	0	0	0	0	0
UPTL1	108-110	0	0	3.333333333	0	0	0	0

SampleName	Depth	Glochidia	Gloetrichia	G. crista	Hippeutis complanata	Juncus	Lemna	Leydigia
UPTL1	1-3	0	0	0	2.272727273	0	0	27.27272727
UPTL1	8-10	23.80952381	0	2.380952381	4.761904762	0	0	0
UPTL1	15-17	60	0	22	4	0	0	2
UPTL1	23-25	428.5714286	1.587301587	149.2063492	11.11111111	1.587301587	0	0
UPTL1	31-33	2166.666667	48.33333333	246.6666667	0	0	0	0
UPTL1	39-41	300	18	44	0	0	0	120
UPTL1	47-49	0	26.5625	7.8125	0	0	0	18.75
UPTL1	55-57	81.96721311	45.90163934	42.62295082	1.639344262	0	0	6.557377049
UPTL1	63-65	0	0	5.454545455	1.818181818	0	0	25.45454545
UPTL1	71-73	34.48275862	8.620689655	1.724137931	0	0	0	25.86206897
UPTL1	78-80	30.76923077	0	3.076923077	0	0	0	52.30769231
UPTL1	85-87	8.333333333	0	0	0	0	1.666666667	28.33333333
UPTL1	92-94	8.333333333	0	0	0	8.333333333	0	8.333333333
UPTL1	100-102	575	3.333333333	3.333333333	0	0	0	0
UPTL1	108-110	508.3333333	3.333333333	31.66666667	10	18.33333333	0	13.33333333

SampleName	Depth	L. crystallinus	Lymnea peregra	N. marina seed	N. marina spine	N. alba seed frag	Orange gelatinous	Oribatei
UPTL1	1-3	0	0	0	56.81818182	0	0	0
UPTL1	8-10	0	0	0	23.80952381	2.380952381	0	47.61904762
UPTL1	15-17	0	16	0	0	0	0	20
UPTL1	23-25	0	98.41269841	0	0	0	0	17.46031746
UPTL1	31-33	0	130	0	0	0	0	88.33333333
UPTL1	39-41	0	136	0	0	4	0	44
UPTL1	47-49	0	150	0	0	0	0	131.25
UPTL1	55-57	0	442.6229508	0	0	0	0	3.278688525
UPTL1	63-65	0	87.27272727	0	0	0	0	72.72727273
UPTL1	71-73	1.724137931	18.96551724	0	0	0	0	17.24137931
UPTL1	78-80	0	96.92307692	1.538461538	0	0	461.5384615	15.38461538
UPTL1	85-87	0	1.666666667	0	0	0	1333.333333	0
UPTL1	92-94	0	0	0	0	0	2500	0
UPTL1	100-102	0	100	1.666666667	0	0	0	0
UPTL1	108-110	0	0	0	0	0	0	16.66666667

SampleName	Depth	Orthotrichia	Percid frag	Percid scale	Phragmites root	Physa	P. geometra	Pisidium
UPTL1	1-3	0	0	0	0	0	2.272727273	0
UPTL1	8-10	0	0	2.380952381	33.33333333	0	0	4.761904762
UPTL1	15-17	2	4	2	4	0	2	0
UPTL1	23-25	0	0	0	49.20634921	7.936507937	0	6.349206349
UPTL1	31-33	0	3.333333333	6.666666667	5	11.66666667	11.66666667	8.333333333
UPTL1	39-41	0	0	0	0	6	12	0
UPTL1	47-49	0	0	0	0	1.5625	10.9375	1.5625
UPTL1	55-57	32.78688525	0	1.639344262	0	0	24.59016393	1.639344262
UPTL1	63-65	10.90909091	0	0	0	0	14.54545455	0
UPTL1	71-73	3.448275862	0	1.724137931	0	0	8.620689655	0
UPTL1	78-80	4.615384615	0	0	0	4.615384615	7.692307692	0
UPTL1	85-87	0	0	0	0	0	0	0
UPTL1	92-94	0	0	0	8.333333333	0	0	0
UPTL1	100-102	8.333333333	0	10	8.333333333	0	1.666666667	3.333333333
UPTL1	108-110	1.666666667	0	3.333333333	0	0	1.666666667	11.66666667

SampleName	Depth	Planorbis albus	P. carinatus	P. planorbis	P. vortex	Pleuroxus truncatus	Plumatella	P.friesii leaf frag
UPTL1	1-3	0	0	0	0	0	45.45454545	0
UPTL1	8-10	4.761904762	0	0	0	23.80952381	154.7619048	0
UPTL1	15-17	16	0	0	0	0	72	2
UPTL1	23-25	84.12698413	0	6.349206349	3.174603175	15.87301587	238.0952381	0
UPTL1	31-33	75	0	0	3.333333333	0	66.66666667	13.33333333
UPTL1	39-41	30	0	0	0	0	130	8
UPTL1	47-49	14.0625	0	1.5625	0	0	218.75	0
UPTL1	55-57	100	0	0	0	0	98.36065574	16.39344262
UPTL1	63-65	3.636363636	0	0	0	18.18181818	381.8181818	3.636363636
UPTL1	71-73	8.620689655	0	0	0	0	68.96551724	0
UPTL1	78-80	7.692307692	0	0	0	0	69.23076923	12.30769231
UPTL1	85-87	0	0	0	0	0	8.333333333	0
UPTL1	92-94	0	0	0	0	0	3.333333333	0
UPTL1	100-102	1.666666667	0	0	0	0	0	0
UPTL1	108-110	8.333333333	8.333333333	10	0	0	16.66666667	0

SampleName	Depth	P. friesii leaf tip	Potamogeton pusillus leaf tip	Potamogeton seed fragment	Prosobranch operculum	Ranunculus	Ranunculus repens	Rotifer egg
UPTL1	1-3	0	0	0	2.272727273	0	0	113.6363636
UPTL1	8-10	0	2.380952381	0	2.380952381	0	0	952.3809524
UPTL1	15-17	0	0	0	6	0	8	0
UPTL1	23-25	1.587301587	0	0	1.587301587	0	0	0
UPTL1	31-33	3.333333333	0	0	10	0	0	0
UPTL1	39-41	4	0	0	8	2	0	0
UPTL1	47-49	0	0	1.5625	1.5625	0	0	0
UPTL1	55-57	1.639344262	14.75409836	0	1.639344262	0	0	0
UPTL1	63-65	0	0	0	5.454545455	0	0	0
UPTL1	71-73	0	0	0	0	0	0	0
UPTL1	78-80	1.538461538	0	0	0	0	0	0
UPTL1	85-87	0	0	0	1.666666667	0	0	0
UPTL1	92-94	0	0	0	6.666666667	0	0	0
UPTL1	100-102	0	0	0	10	0	0	0
UPTL1	108-110	0	0	0	20	0	0	0

SampleName	Depth	S. lacustris	Simocephalus	small Pot seed	Sphagnum leaf	Sponge balls	S. aloides spine	Trichoschleroid
UPTL1	1-3	0	2.272727273	0	0	2.272727273	0	0
UPTL1	8-10	0	0	0	0	30.95238095	0	0
UPTL1	15-17	0	2	0	0	56	0	0
UPTL1	23-25	0	0	0	0	0	0	0
UPTL1	31-33	0	3.333333333	0	0	0	0	36.66666667
UPTL1	39-41	0	0	0	0	0	2	44
UPTL1	47-49	0	1.5625	0	0	0	0	125
UPTL1	55-57	0	0	6.557377049	0	0	398.3606557	0
UPTL1	63-65	0	0	0	0	0	63.63636364	0
UPTL1	71-73	0	0	0	0	0	1.724137931	0
UPTL1	78-80	0	15.38461538	0	0	0	35.38461538	0
UPTL1	85-87	0	0	0	5	0	0	0
UPTL1	92-94	0	0	0	0	0	0	0
UPTL1	100-102	0	0	0	80	0	0	0
UPTL1	108-110	6.666666667	3.333333333	0	403.3333333	0	8.333333333	0

SampleName	Depth	Typha	Valvata cristata	Valvata macrostoma	Valvata piscinalis	Zannichellia palustris seed
UPTL1	1-3	0	0	0	0	11.36363636
UPTL1	8-10	0	2.380952381	0	4.761904762	21.42857143
UPTL1	15-17	2	2	2	0	10
UPTL1	23-25	15.87301587	7.936507937	3.174603175	15.87301587	6.349206349
UPTL1	31-33	0	16.66666667	1.666666667	15	6.666666667
UPTL1	39-41	0	10	8	2	0
UPTL1	47-49	0	7.8125	1.5625	6.25	0
UPTL1	55-57	0	8.196721311	0	14.75409836	1.639344262
UPTL1	63-65	0	0	7.272727273	10.90909091	0
UPTL1	71-73	0	1.724137931	0	0	0
UPTL1	78-80	0	1.538461538	1.538461538	3.076923077	0
UPTL1	85-87	0	0	0	0	0
UPTL1	92-94	8.333333333	0	0	1.666666667	0
UPTL1	100-102	0	5	3.333333333	5	0
UPTL1	108-110	0	8.333333333	8.333333333	25	0