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Introduction

A palaeoecological study of a single wetland site, Boxford Water Meadows in England, was conducted to explore the potential of sediment records from wetlands for assessing long-term, nutrient-climate change interactions. The methods for using lake sediment cores to assess changes in lake level associated with climate (e.g. Fritz et al. 1999) and changes in trophic status associated with nutrient inputs (e.g. Hall and Smol 1999) are well established. However, the potential for employing sediment cores from wetlands to assess these environmental impacts has until now not been explored. Wetland sediments are likely to be more disturbed than deep lake sediments and, therefore, this task aimed to evaluate whether they are suitable for palaeoecological investigations of this kind. This paper highlights the potential and problems of inferring environmental change in a riparian wetland using a palaeoecological approach.

Study site description

Boxford Water Meadows (UK grid reference SU 428719) is a Site of Special Scientific Interest (SSSI) covering an area of approximately 14 hectares (Figures 1 & 2). The site comprises a series of flood pastures and disused water meadows along the River Lambourn. The site overlies alluvium and the soils consist of calcareous alluvial gleys. Traditionally the water meadows would have been managed as pasture for cattle or horses with controlled flooding along specially constructed carrier streams providing a supply of warm water in spring to encourage early growth of the sward. The meadows have not been grazed, with the exception of the southern-most field, for around 40 years and the vegetation types reflect both this and the gradient in soil moisture. The plant communities grade from Carex acutiformis swamp-fen to Cynosurus cristatus-Caltha palustris flood-pasture and water-meadow vegetation southwards across the site.

Methods

Core collection and lithostratigraphy

A total of eight cores were taken along a south to north transect on the west side of the river on 27th April 2005 using a gouge coring device (Figure 3). Core site 8 at the northern-most end of the transect (grid reference SU 42880, 72213) was selected as the site for further study owing to it’s location on the site of an old river channel, the depth of sediment accumulation and the interesting stratigraphic changes observed. Hence, two overlapping drives with a standard Russian corer were taken and the core was coded BOXF1. Drive 1 covered the section from the sediment surface to a depth of 50 cm and drive 2 covered the section 40-90 cm (Figure 4). The core was extruded into plastic holders, wrapped in cling-film and transported to the laboratory for analysis.

In the laboratory, drive 1 of core BOXF1 was subsampled at 0.5 cm contiguous intervals from 0-50 cm and drive 2 was subsampled at 1 cm contiguous intervals from 50-90 cm. The main characteristics of the sediment and any stratigraphic changes were noted. The percentage dry weight (DW %) which gives a measure of the water content of the sediment, and percentage loss on ignition (LOI 550) which gives a measure of the organic matter content were determined for all subsamples, and carbonate content was determined for the section 40-90 cm only. All analyses followed standard techniques (Dean 1974).

Chronology

An approximate chronology for the core was established using spheroidal carbonaceous particles (SCPs) (Rose 1994). In addition, sediment samples from BOXF1 were analysed for 210Pb, 226Ra, 137Cs and 241Am by direct gamma assay in the Bloomsbury Environment Institute at University College London (Appleby et al. 1986) in an attempt to provide a further independent chronology for the core.
Biological analyses
A total of 23 sub-samples were prepared and analysed for diatoms using standard methods (Battarbee et al. 2001). At least 300 valves were counted in each sample except where preservation was exceptionally poor and in some cases only ~100-200 valves could be found on the whole slide. Principal floras used in identification were Krammer and Lange-Bertalot (1986-1991). The diatom data were expressed as percentage relative abundance. A diatom-total phosphorus (TP) transfer function was applied to the diatom data following taxonomic harmonisation between the training set and the fossil data. Reconstructions of diatom-inferred TP (DI-TP) were produced using 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 0.21 log₁₀ µg TP l⁻¹ for the weighted averaging partial least squares component 2 (WA-PLS2) model (Bennion et al. 1996).

Ten sub-samples at 10 cm intervals throughout the core were prepared and analysed for cladocera. The samples (approximately 1 g wet weight) were boiled in 30 ml 10% KOH for ~20 min and subsequently kept cold for no longer than two weeks before counting. After manual filtering, fragments larger than 80 µm were counted and identified using a stereomicroscope and an inverted light microscope. For the identification, keys of Frey (1959), Margaritora (1985), Hann (1990), Røen (1995) and Flössner (2000) were used. The cladocera data were expressed as numbers per gram dry weight and were subsequently converted into relative percentage abundance values.

The resulting diatom and Cladocera profiles were zoned based on cluster analysis to facilitate description and allow comparison of the two datasets. Cluster analysis was performed using CONISS (Grimm 1987), implemented by TILIA and TILIAGRAPH (Grimm 1991). CONISS is a program for stratigraphically constrained cluster analysis by the method of incremental sum of squares.

It was anticipated at the outset of the project that ostracods may be particularly useful for identifying periods of wetting and drying of the wetland versus permanently wet episodes. Therefore, wet sub-samples from BOXF1 were sieved at 125 µm by UCL to assess the amount of ostracod and mollusc remains. Unfortunately, only a few shells and fragments were found and ostracods were generally rare and poorly preserved. Calcareous remains were absent from the upper peat section, most likely as a result of post depositional dissolution. However, in the chalky, limnic sediments from 76 cm to the base ostracod and mollusc remains were found although preservation was poor. Even the smaller mesh size of 80 µm, employed during the cladoceran analysis, failed to find more than a few fragments of ostracods in the 40-90 cm section and they were absent in the upper 40 cm. The lack of such remains throughout the core sequence made it impossible to pursue carbonate isotope analysis. Likewise, it was originally hoped that plant macrofossils could be analysed to assess shifts in vegetation but unfortunately insufficient remains were present in the core to pursue this method.

Results and discussion
Stratigraphy
The upper 25 cm of drive 1 was a dark brown, sedge peat with abundant root linings (Figure 5). The uppermost 16 cm had a very high organic content of ~80%, gradually decreasing to ~30% over the section 16-25 cm. The colour grades from dark brown to a lighter brown at ~25-30 cm and the light brown sedge peat then continues for a large section of the core sequence from ~25-70 cm. Organic matter content remained at ~30% from 25-57 cm but then declined to ~10-15% coincident with the presence of mineral fragments and chalk particles in the section 58-70 cm. From 70-80 cm, the sediment becomes lighter in colour and is comprised of a chalky mud matrix. The carbonate content fluctuates between ~10-20% over the section 40-80 cm. At 80 cm there was a marked change to a coarse chalk aggregate which was white in colour and consequently carbonate content rises to ~30-35%. The lowermost 10 cm were comprised of a fine grained calcareous mud with chalk clasts.
Chronology
Owing to very low concentrations, $^{210}$Pb dating of the BOXF1 core was not possible. However, a $^{137}$Cs peak was identified at 5.5-6 cm and, whilst this should be interpreted with caution, it is likely to represent 1963, the year of peak fallout from the atmospheric testing of nuclear weapons.

The core BOXF1 contains the full SCP record indicating that it covers the last $\sim$150 years (Figure 6). In spite of being taken from a riparian wetland rather than from a lake basin, the SCP record exhibits features that are recognisable in many lake sediment cores across the UK and Europe (Rose et al. 1995). However, a large peak occurred at 14 – 14.5 cm and it is unclear whether this is a real peak or an analytical artefact owing to relatively low sample resolution. Nevertheless, three dates representing the start of the SCP record, the start of the rapid increase in concentration and the SCP concentration peak could be ascribed to this profile (Figure 7). These data suggest a reasonably linear accumulation over the last 150 years and show agreement with the limited radiometric data ($^{137}$Cs peak) and, when extrapolated, the date of coring. This being the case, a mean sedimentation for BOXF1 over the last 150 years is $\sim$ 0.148 cm yr$^{-1}$.

Biological analyses
Diatoms were present in all of the samples although at varying degrees of preservation. A total of 88 diatom taxa were observed in the core although individual samples were not particularly diverse containing between 20 and 38 taxa. The cluster analysis identified six zones (Figure 8).

In Zone 1 (below 62 cm), the frustules in the lowermost sample (88-90 cm) which represents the most calcareous section of the core, were very well preserved. In contrast, the other samples in this zone contained high amounts of mineral matter and relatively few complete frustules. This zone was dominated by benthic Fragilaria spp, namely Fragilaria pinnata, Fragilaria brevistriata and Fragilaria construens var venter, which are cosmopolitan taxa commonly observed in relatively productive, alkaline shallow waters (Bennion et al. 2001). The other taxa present were all non-planktonic forms commonly found attached to plant, stone or mud surfaces, including Cocconeis (disculus and pseudothumensis), Amphora pediculus, a number of small Navicula species (subatomoides, menisculus and subrotundata), Gyrosigma attenuatum and Achnanthes clevei. The DI-TP values were high, fluctuating between $\sim$150-190 $\mu$g l$^{-1}$.

In Zones 2 and 3 (62-15 cm) which represent the period prior to $\sim$1900 AD, diatom preservation was highly variable. As in Zone 1, the assemblages were dominated by Fragilaria taxa. However a number of taxa that had been relatively abundant in Zone1 decreased, particularly Cocconeis disculus, Cocconeis pseudothumensis, Amphora pediculus, Navicula menisculus, Navicula subrotundata, Gyrosigma attenuatum and Achnanthes clevei. Conversely, Synedra ulna, Cyclotella radiosa and Meridion circulare increased. Cyclotella radiosa is a planktonic species whilst Synedra ulna and Meridion circulare are common river diatoms and, therefore, the expansion of these taxa could signify an increase in water level from inputs of river water to the wetland. The DI-TP values were similar to those in Zone 1, ranging from $\sim$160-200 $\mu$g l$^{-1}$ in Zone 2 and $\sim$150-160 $\mu$g l$^{-1}$ in Zone 3.

Zones 4 to 6 (15-0 cm) represent the period from $\sim$1900 AD to present which coincides with the dark brown sedge-peat, and here the diatoms were poorly preserved. The benthic Fragilaria taxa remained dominant in all except the surface sample. The most notable change in these upper zones was the marked increase in Achnanthes lanceolata and Fragilaria nitzschioides and, to a lesser extent, Fragilaria capucina which, based on the ecology of these taxa, would indicate an increase in nutrient levels. This is reflected in the DI-TP values which increase towards the top of the core to values of $\sim$190 $\mu$g l$^{-1}$. Conversely the relative abundances of Synedra ulna and Cyclotella radiosa declined which may reflect lower water levels than in Zones 2 and 3.

The Cladocera analyses identified a total of 19 different types of remain distributed among 12 taxa. The whole core was dominated by macrophyte associated and benthic chyadorids and no true pelagic taxa were present indicating low water level throughout the period represented by the sediment record. Cluster analysis identified three major zones (Figure 9).
Zone 1 (90-75 cm) contained very few Cladocera fragments. The basal sample, the most calcareous section of the core, was comprised of *Pleuroxus* spp and *Chydoridae* spp. In Zone 2 (75-15 cm), *Chydoridae* spp. continued to be abundant but there were higher abundances of *Alona affinis* and *Acroperus* spp. relative to Zone 1 which could indicate an increase in the water level as these species are typically associated with macrophytes or with the sediment around macrophytes, and aquatic plants would need sufficient water depth to survive. The samples in Zone 3 (15-0 cm) were coincident with the dark brown sedge-peat and saw the disappearance of *Alona affinis* and expansion of *Alona quarangularis*. Whilst Cladocera remains have not previously been analysed in wetland complexes such as Boxford, in lakes this shift would indicate a reduction in plant cover typically associated with an increase in nutrient concentrations. Therefore, in recent times the wetland may have received water with higher nutrient concentrations than in the past.

**Comparison of diatom and cladocera results**

There is reasonable agreement between the timing and nature of the main shifts in the diatom and Cladocera assemblages although both sets of data are difficult to interpret in the context of hydrological fluctuations or productivity changes. The assemblages of both biological groups are dominated by non-planktonic taxa throughout the record indicating that water levels have not altered dramatically during the period represented by the core. However there is a slight increase in planktonic diatom forms in the middle of the sequence (55-25 cm), namely *Cyclotella radiosa* and *Synedra ulna*, and this overlaps with the increased amounts of *Alona affinis* and *Chydorus* spp., which could suggest that water levels were higher at this time. Both the diatom and the Cladocera assemblages change in the upper 15 cm (post-1900) which appears to signify nutrient enrichment.

**Conclusions**

The shifts in the diatom and Cladocera assemblages were difficult to interpret in the context of hydrological fluctuations or productivity changes. Nevertheless, the coherence in the biological records and the success in dating the core using the SCP method suggest that sediment cores from riparian wetlands can potentially be used for palaeoenvironmental reconstruction. However, the study highlights the need for very careful site selection and screening of material to ensure that sufficient remains of the proxies of interest are preserved. Further ecological studies of the key diatom and Cladocera taxa are required to interpret the findings more fully.
References


Rose NL (1994) A note on further refinements to a procedure for the extraction of carbonaceous fly-ash particles from sediments. J Paleolimnol 11: 201-204

Figure 1 Aerial photograph of Boxford Water Meadows, Berkshire

Figure 2 Photograph of a) coring site at Boxford Water Meadows, and b) River Lambourn adjacent to coring site
Figure 3 Map showing the location of the coring transect and site of the Russian core BOXF1. The GPS coordinates of core BOXF1 and the core transect are overlaid on an Ordnance Survey map from 1882. Channels within the water meadows on the west side of the river are clearly visible.

Figure 4 Photographs of Boxford Water Meadows core BOXF1, a) drive 1 (0-50 cm) and b) drive 2 (40-90 cm)
Boxford Water Meadows, Dry weight, LOI & Carbonate content (40 - 90 cm only)

Figure 5 Summary stratigraphic diagram of Boxford Water Meadows core BOXF1
Carbonate content analysis carried out on the 40-90 cm section only; no carbonate data for 0-40 cm section
DW, LOI 550 and carbonate content data are all expressed as percentages.
Figure 6 Spheroidal carbonaceous particle concentration results for BOXF1

Figure 7 Depth-age profile for BOXF1 showing SCP data, the best available date from the 137Cs data, and the coring date
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<th>Navicula subbotanoides</th>
<th>Aulacoseira granulata</th>
<th>Navicula meniscostrata</th>
<th>Cocconeis pseudodeltoidea</th>
<th>Navicula naviculoides</th>
<th>Fragilaria crotonensis</th>
<th>Achnanthes cleveii</th>
<th>Amphora petersiana</th>
<th>Fragilaria capucina</th>
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<td>Amphora petersiana</td>
<td>Fragilaria capucina</td>
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Figure 8 Summary diatom stratigraphy for core BOXF1
Figure 9 Summary Cladocera stratigraphy for core BOXF1
Note that taxa are represented by head capsules in all samples except for *Chydorus* spp. (0-70 cm), *Alonella nana* (70 cm), *Graptoleberis testudinaria* (30 cm), *Pleuroxus trigonellus* (10 cm), *Pleuroxus uncinatus* (50 cm), *Pleuroxus* spp. (10-20 cm) which are represented by carapaces, and *Simocephalus* sp. (1 cm) which is represented by ephippia