The Environmental History of Kenfig Pool, cSAC

T. Davidson & P.G. Appleby

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Executive summary

1. This is the final report to the Countryside Council for Wales under contract FC 73-01-385: The environmental history of Kenfig Pool, cSAC, a shallow lake in Kenfig National Nature Reserve.

2. The study employed palaeolimnological techniques to evaluate the degree of environmental change at Kenfig Pool, based on the analysis of one sediment core, KENF2.

3. The report describes the lithostratigraphy and presents the results of Charophyte oospore and cladoceran remains analysis, for 15 levels from the sediment core. Radiometric dating was also carried out in an attempt to establish a chronology and estimate sediment accumulation rates for KENF2.

4. The dating results indicated a small but significant increase in sediment accumulation rates over last two decades. The radiometric dating becomes unreliable below around 30 centimetres making it difficult to ascribe dates to the lower parts of the core. The accumulation rates derived for the top sections cannot be assumed to be the same for the lower parts, particularly given the marked changes in stratigraphy.

5. The Charophyte oospore profile, combined with the other larger plant and animal remains identified, suggests a significant shift in the aquatic macrophyte community over the time period represented by the core. The record indicates an early abundance of *Characeae* followed by an overall decline in both the diversity and abundance of in the last 70 years.

6. The cladoceran stratigraphy, represented by both ephippia and chitinous remains, showed significant changes in community structure over the time period represented by the core. The data suggest changes in macrophyte structure and abundance and a dramatic increase in fish predation since approximately 1960. There is evidence of a decline in this predation pressure in the top ten centimetres of the core which represents approximately the last 15 years.

7. The results of this investigation are placed within the context of the use of the site as a fishery resource and the recorded stocking events. The palaeolimnological data appear to reflect a historical rise in nutrient levels, or a change in lake morphology, leading to the proliferation of *Characeae.* Later in the sequence there is an increase in fish predation pressure, the effects of which have cascaded down the trophic levels, perhaps reducing the conservation value of the site.

8. Recommendations for site management are made in the context of the recent fishery management plan for Kenfig Pool compiled by Nick Giles and Associates. The overall aims of the management plan are endorsed with an appropriate target fish community for a plant dominated shallow lake suggested. The importance of maintaining a healthy piscivore community, particularly perch, to control the small zooplanktivorous rudd is stressed.

Crynodeb Gweithredol

1. Dyma'r adroddiad terfynol i Gyngor Cefn Gwlad Cymru dan gontract FC 73-01-385 : Hanes amgylcheddol Pwll Cynffig, yACA, pwll bas yng Ngwarchodfa Natur Genedlaethol Cynffig.

2. Mae'r adroddiad yn defnyddio technegau palaeohinsoddol i bwyso a mesur maint y newid amgylcheddol ym Mhwll Cynffig, yn seiliedig ar ddadansoddiad o un craidd gwaddod, KENF2.

3. Mae'r adroddiad yn disgrifio lithostatigraffeg ac yn cyflwyno canlyniadau dadansoddiad öosbor Charophyte a data y chwannen ddŵr ar gyfer 15 lefel o'r craidd gwaddod. Aethpwyd ati i ddyddio'n radiometrig hefyd er mwyn ceisio sefydlu cronoleg ac amcangyfrif cyfraddau croniad gwaddod ar gyfer KENF2.

4. Roedd canlyniadau'r dyddio yn dangos cynnydd bychan ond arwyddocaol yng nghyfraddau croniad gwaddod dros y ddau ddegawd. Nid yw dyddio radiometrig yn ddibynnol o dan tua 30 centimetr gan ei gwneud yn anodd nodi dyddiadau i rannau is y craidd. Ni ellir cymryd yn ganiataol mai'r un yw cyfraddau croniad rhannau is y craidd â chyfraddau croniad y rhannu uchaf, yn enwedig o ystyried y newidiauau sylweddol yn y stratigraffeg.

5. Mae'r proffil oospore Charophyte, ynghyd â'r gweddillion mwy eraill o blanhigion ac anifeiliaid sydd wedi'u nodi, yn awgrymu symudiad arwyddocaol yn y gymuned ddyfrdrig macroffyt dros y cyfnod o amser sy'n cael ei gynrychioli gan y craidd. Mae'r cofnod yn awgrymu helaethrwydd cynnar o *Characeae* yn cael ei ddilyn gan leihad cyffredinol yn amrywiaeth a helaethrwydd y *Characeae* dros y 70 mlynedd ddiwethaf.

6. Roedd stratigraffeg y chwannen ddŵr, oedd yn cael ei chynrychioli gan weddillion ephippiaidd a chitinaidd, yn dangos newidiadau arwyddocaol yn strwythur y gymuned dros y cyfnod o amser oedd yn cael ei gynrychioli gan y craidd. Mae'r data yn awgrymu newidiadau yn y strwythur a'r helaethrwydd macroffyt a chynnydd dramatig mewn ysglyfaethu pysgod er tua 1960. Ceir tystiolaeth fod llai o bwysau oherwydd yr ysglyfaethu yma yn neg centimetr uchaf y craidd sy'n cynrychioli oddeutu'r 15 mlynedd ddiwethaf.

7. Mae canlyniadau'r ymchwiliad yma'n cael eu gosod o fewn cyd-destun y defnydd o'r safle fel pysgodfa a'r adegau sydd wedi'u cofnodi pan aethpwyd ati i stocio. Mae'r astudiaeth bresennol i'w gweld yn adlewyrchu cynnydd hanesyddol mewn lefelau maetholion neu newid ym morffoleg y llyn. Mae hyn yn arwain at amlder *Characeae* ac yna at fwy o ysglyfaethu pysgod, effeithiau'r hyn sydd wedi rhaeadru i lawr y lefelau trophig gan efallai leihau gwerth cadwraethol y safle.

8. Gwneir argymhellion ar gyfer rheolaeth y safle yng nghyd-destun y cynllun rheoli pysgodfeydd a baratowyd yn ddiweddar ar gyfer Llyn Cynffig gan Nick Giles and Associates. Mae nodau cyffredinol y cynllun rheolaeth yn cael eu cymeradwyo fel cymuned bysgod addas ar gyfer pwll bas wedi'i oruchafu gan blanhigion. Pwysleisir pwysigrwydd cynnal cymuned bysgysol iach, yn enwedig draenogiaid, i reoli'r rhuddbysgod söoplancton.

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1 Introduction

1.1 Site description

Kenfig Pool (SS 790 820) is a shallow (max. depth = 2.6m) moderately large (24 ha) lake situated within the extensive sand dune system of the Kenfig National Nature Reserve, alongside Swansea Bay, south Wales. The Pool is thought to be around 7,500 years old, being created in association with sand dune formation in Swansea Bay (Giles, 2003). It is the largest freshwater lake in the old county of Glamorgan. The site is noted for its aquatic macrophyte flora and is an important site for over-wintering wildfowl.

The water chemistry is characteristic of an alkaline lake with a moderate nutrient status. High alkalinity, conductivity, sodium and chloride values reflect the proximity to the sea and elevated calcium values may well be the result of marine shell remains in the sandy substrate. Kenfig Pool is an important conservation resource and is a relatively unique habitat type, not only in Wales, but also in the UK as a whole. It was designated as a Site of Special Scientific Interest in 1953, a National Nature Reserve in 1989 and is currently a candidate Special Area of Conservation (cSAC) for the hard oligo-mesotrophic waters with benthic vegetation of *Chara* formations. The open-water macrophyte community includes: *Ceratophyllum demersum* (rigid hornwort), *Ranunculus circinatus* (fan-leaved water-crowfoot), *Myriophyllum spicatum* (spiked water-milfoil), *Potamogeton crispus* (curled pondweed), *P. lucens* (shining pondweed), *P. pectinatus* (fennel-leaved pondweed), *P. trichoides* (hairlike pondweed), *Littorella uniflora* (shoreweed), *Chara aspera* var. *aspera, Nitella flexilis*, and along the sandy shore section, the aquatic moss *Fontinalis antipyretica* (ENSIS, 1996).

As with most still waters in lowland areas the site may have been subjected to increased levels of plant nutrients over the past 100 years (Wetzel 1983; Moss, 1998). The hydrological catchment of the pool is difficult to define, given the gradual slope of the catchment and the unknown extent of the drainage systems leading from the M4 motorway (ENSIS, 1996). The pool appears to be fed by dune seepage, three small ephemeral streams, and possibly a deep Carbonaceous Limestone aquifer. The streams are thought to be a source of plant nutrients and in 1984 may have received some inputs from waste paper sludge which was spread on adjacent fields. The aquifer may be a threat in that it could convey various pollutants from landfill quarries (ENSIS, 1996). Notwithstanding these threats, water quality of the site remains good, with relatively low conductivity and total phosphorus (TP) concentrations (mean values from 1995-1996, 345 $\mu S\ cm^{-1}$ and 32 $\mu g\ l^{-1}$ respectively).

Previous palaeolimnological work at the site demonstrated that sedimentary diatom preservation was poor (Allot *et al*., 2001). The application of diatom based models developed to quantitatively reconstruct TP (Bennion, 1994) was, therefore, not possible. Even in the event of perfect diatom preservation, the technique may not have been appropriate to this study as there are problems associated with diatom TP inference models in shallow lakes, in particular, macrophyte rich sites where non-planktonic *Fragilaria* taxa often dominate (Sayer, 2001; Bennion *et al*., 2001a). Additionally, as discussed below, changes in lakewater TP do not necessarily reflect changes in overall lake ecology.

1.2 Kenfig Pool fishery

Kenfig Pool is a valued resource for anglers and has been the subject of fish stocking for at least 50 years, with anglers records dating back to the beginning of the 20th century (Giles, 2002). The management of the lake as a fishery resource has potentially serious implications for the conservation value and the ecological quality of the site. The implementation of the EU Water Framework Directive also has many implications for the management of such a valuable site, particularly given its status as a cSAC.

1.3 Project rationale

Scheffer *et al*. (1993) state that shallow lakes exist in two distinct states. A clear water state with a diverse array of aquatic macrophytes where algal biomass is limited and the obverse state where submerged plants are absent and primary production is dominated by phytoplankton, resulting in turbid waters. The underlying factor determining which state a lake will occupy is nutrient concentration. Elevated phosphate and nitrate concentrations generally lead to higher phytoplankton biomass (Phillips *et al*., 1978), increasing the propensity of a lake to exist in the turbid state. Empirical evidence, however, has demonstrated that ecological state is not solely dictated by nutrient levels, the same concentrations resulting in both clear water and turbid states (Scheffer, 1993). There are a number of biological feedback mechanisms which maintain a system in one stable state or the other, the breakdown of which leads to a 'switch' between states.

Fish play a critical role in determining the structure, function and stability of shallow lake ecosystems (Persson *et al*., 1988; Lammens, 1999). Fish exert their influence through feeding strategies, generally by reducing the zooplankton population to the point where it is too small to control the phytoplankton biomass. This 'fish effect' thus cascades through the trophic levels affecting algal abundance and even nutrient availability (Carpenter *et al*., 1985). Additionally, changes in fish community structure are associated with the eutrophication process, characterised by a reduction in piscivorous fish abundance and an increase in the proportion of zooplanktivorous and/or benthivorous fish (Jeppesen, 1998). This shift in fish population composition may be a factor in inducing the switch from a clear water to turbid state (Brönmark & Weisner, 1992).

Macrophytes and mosses can potentially colonise large areas of the lake bed in shallow lakes such as Kenfig Pool. Aquatic plants are significant as habitat, food source and refuge for numerous consumers, and have an essential structuring role on the whole ecosystem (Carpenter & Lodge, 1986, Jeppesen *et al*., 1998). Additionally, submerged plants also affect the interactions between these consumers, the effects on zooplankton-fish interactions are of particular relevance to this project.

Macrophytes, fish and their interactions are of key importance to determining the ecological state and conservation value of ecosystems such as Kenfig Pool; they are key factors in structuring the cladocera community (Jeppesen *et al*., 1998). Thus, the fossil cladocera community may reflect any changes in past fish populations. Information on the historical changes in fish predation pressure and the effect this had on the rest of the biological community, such as *Chara spp.* populations, would be extremely useful for successful management of the site. Palaeolimnological techniques can be used to determine currents trends and rates and causes of environmental change and to define restoration targets where sites have been disturbed (Battarbee, 1999).

1.4 Project objectives

1. Establish a dated chronology for the sediment profile.

2. Analyse selected microfossil (Cladocera) and macrofossil assemblages (*Chara* oospores) from the lake sediment core.
3. Relate any changes in sedimentary assemblages to corresponding changes in fish community, especially shifts in the ratio of zooplanktivorous to piscivorous fish.
4. Set out how the findings of this research may help assess the ecological quality of Kenfig Pool under the Water Framework Directive, establish the past or potential degree of impact of fishery management and contribute to the development of conservation objectives and the future management of the site, including fishery development.

2 Methods

2.1 Coring and lithostratigraphic analyses

A sediment core was retrieved from the open water area of Kenfig Pool on the 10/7/2002 using a fat piston corer, at a water depth of 2.5 m. The core was 78 cm in length and was coded KENF2.

The percentage dry weight (% dw) for each sample was calculated by weighing approximately 1g of wet sediment in a pre-weighed crucible, from each pre-homogenised sediment layer, drying the sediment at 105 °C for at least 16 hours, then reweighing the crucible. Approximate organic matter content was then determined (as a percentage loss on ignition % loi) by placing the crucible containing the dried sediment in a muffle furnace at 550 °C for two hours and then reweighing. The carbonate content was calculated by returning the crucible to the furnace for two hours at 925 °C and then reweighing.

2.2 Dating

Sediment samples from Kenfig pool core KENF2 were analysed for ^{210}Pb, ^{226}Ra, and ^{137}Cs by direct gamma assay in the Liverpool University Environmental Radioactivity Laboratory, using Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detectors (Appleby *et al*., 1986). ^{210}Pb was determined via its gamma emissions at 46.5keV, and ^{226}Ra by the 295keV and 352keV γ-rays emitted by its daughter isotope ^{214}Pb following 3 weeks storage in sealed containers to allow radioactive equilibration. ^{137}Cs was measured by its emissions at 662keV. The absolute efficiencies of the detectors were determined using calibrated sources and sediment samples of known activity. Corrections were made for the effect of self-absorption of low energy γ-rays within the sample (Appleby *et al*., 1992).

2.3 Oospore analysis

In the absence of reliable information on past aquatic plant communities, analysis of sedimentary macro-remains (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, Odgaard *et al*., 1997). This study focussed specifically on the sedimentary remains of *Characeae*. It is generally assumed that plant macrofossils do not move far from their point of production. Charophyte oospores, however, are often relatively well distributed across a lake basin, even when extant communities are relatively localised (Zhao *et al*., 2001). Interpretation of oospore numbers is based on the assumption that number of oospores left in the sediments is a reflection of the success of that species. Work on the fox-tailed stonewort *Lamprothamnium papulosum* has shown this assumption to be true for surface sediments (Martin, 2001). The use of plant macrofossils as a tool for tracking shifts in macrophyte populations is still in development but initial studies suggest the technique can reliably infer temporal changes in dominant components of the aquatic vegetation for small shallow lakes (Bennion *et al.*, 2001b).

In this study 15 levels from KENF2 were examined for macrofossils. The surface sediment sample had insufficient material so the adjacent sample (1-2 cm) was analysed. Sub-samples of approximately 20 cm^3 were washed through a 200 micron sieve, the exact sample volume being measured by water displacement, and weighed. The entire residue on the 200 micron sieve was examined under a stereo-microscope at magnifications of 10-40 and the charophyte fossils, along with any aquatic macrophyte seeds enumerated.

Cluster analysis was performed on the macrofossil data to facilitate a description of zones for KENF2, using CONISS (GRIMM, 1987) implemented by TILIA and TILIAGRAPH (Grimm, 1991). CONISS is a programme for stratigraphically constrained cluster analysis by the method of incremental sum of squares. The data were square root transformed prior to the analysis in order to fit the assumptions of the technique.

Further to the analysis carried out as part of this project, samples from the core were used as part of a training course in macrofossil analysis. Whilst the analysts were only trainees the data they generated may be useful in terms of the large plant remains which were identified by the more experienced analysts running the course.

2.4 Cladocera analysis

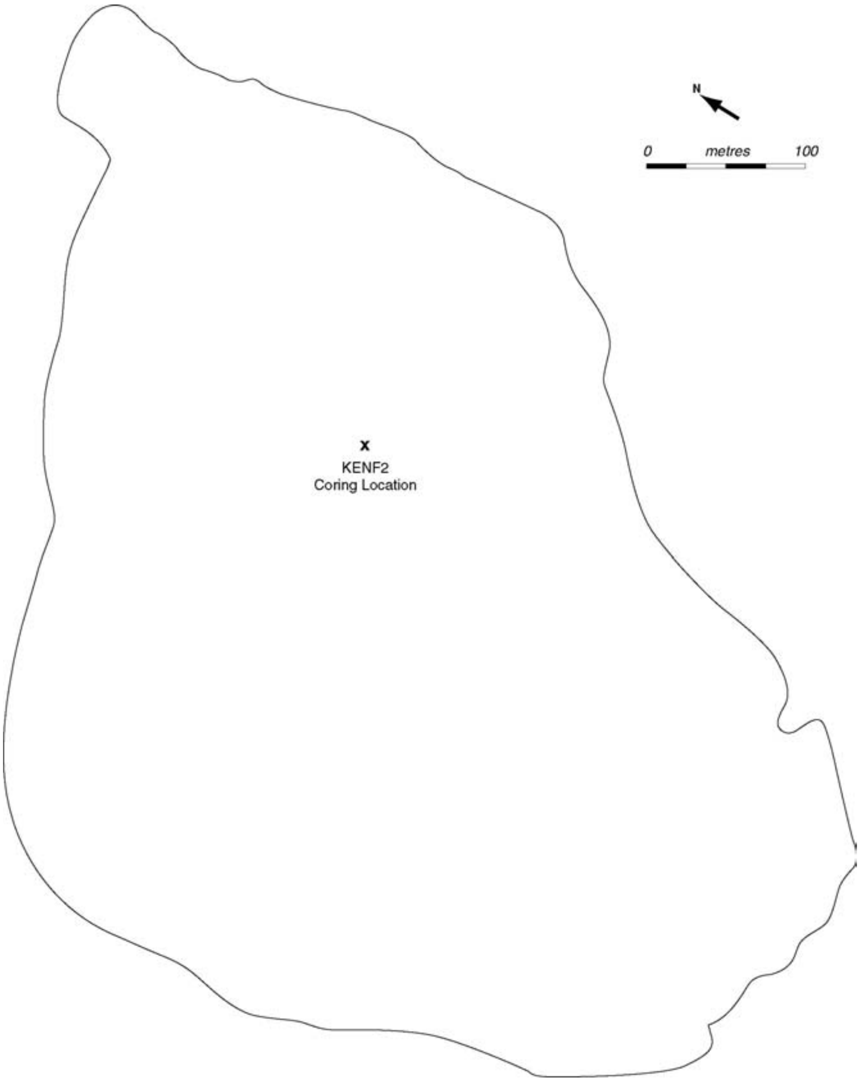
Cladocera remains were analysed using an adaptation of standard techniques (Frey, 1986; Korhola & Rautio, 2000). Ephippial remains were separated and counted along with oospore remains using a binocular microscope, thus the counts are based on the analysis of at least 20 cm^3 of sediment and are expressed as numbers per 100 cm^3. Chitinous remains: head shields; carapaces and post abdomens along with small ephippia were counted using a light microscope at x 40 to 400. Remains were identified using the floras of Frey (1958, 1959, 1964), Flössner (1972) and Alonso (1996). Counting of individuals followed the minimum number method: head shields, carapaces and post abdominal claws were tabulated separately, the count for each species being the number of the most numerous remain. The occurrences of the various taxa represented by chitinous remains were expressed as percentages or relative abundances. *Ceriodaphnia* spp. ephippia were found in both types of analysis, these data were however treated separately as the amalgamation of data from the two techniques is problematic.

The sedimentary cladoceran record, based in chitinous remains alone, is incomplete, with a greater diversity of littoral chydorids being preserved compared to planktonic cladocerans (Hoffman, 1987; Hann *et al.*, 1994). Planktonic cladocera, particularly large bodied species, are most susceptible to fish predation (Brooks & Dodson, 1965; Hrbácek *et al.*, 1961). Thus, in order to determine the past effects of fish on the sediment record an adapted technique, in which ephippia were enumerated, was employed.

Cluster analysis was performed on the percentage cladocera data (square root transformed) to facilitate a description of zones for KENF2, using CONISS, as before.

3 Results

Figure 1 Coring location at Kenfig Pool, KENF2



3.1 Lithostratigraphy and dating

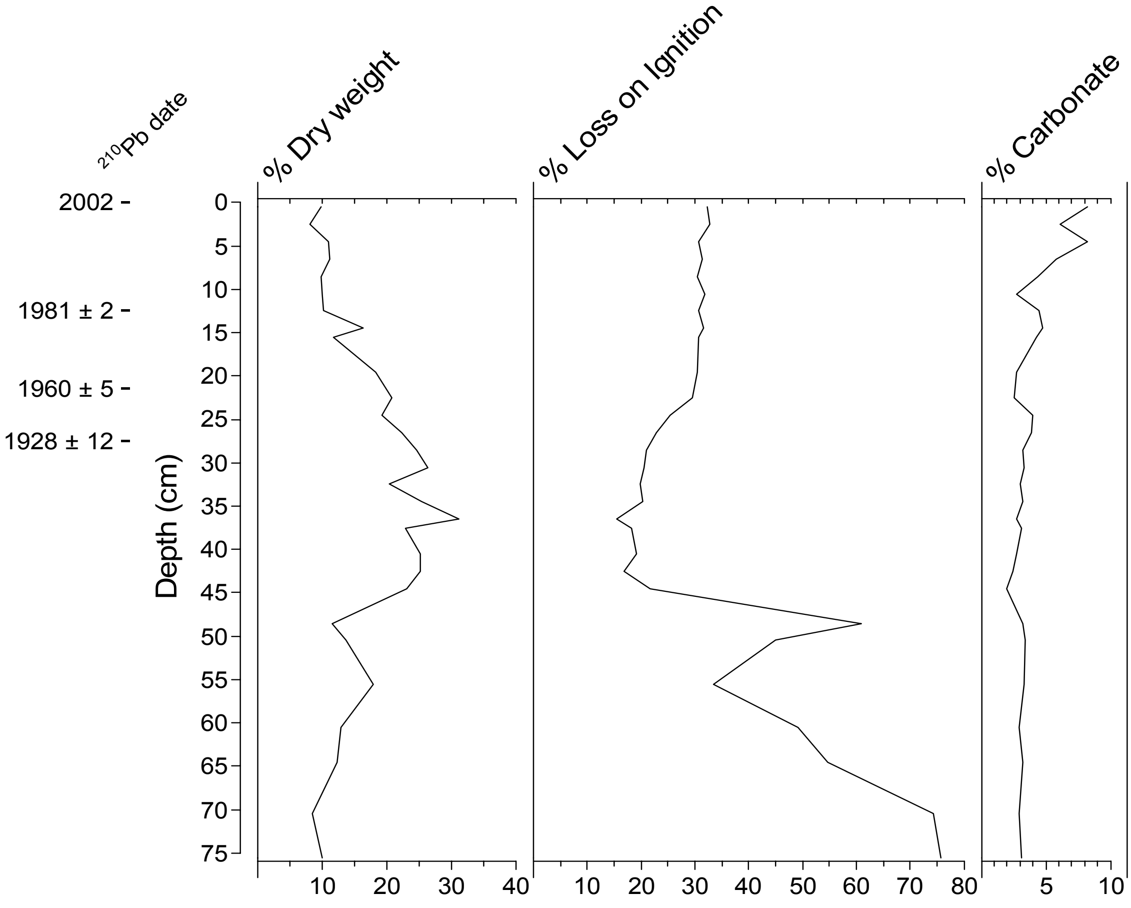
KENF2, a 78 cm core, was taken in July 2002 from of the northern end (Figure 1) of Kenfig Pool using a fat piston corer in 2.5m of water. The main features of the sediment stratigraphy are described in Table 1.

The lithostratigraphy is shown in Figure 2. The % dry weight remained relatively stable from 75 cm to 50 cm, after which there was an increase from 10 % to a peak of 30% a 35 cm. Above 35 cm there was a constant decline to approximately 10% at the surface. Percentage loss on ignition also displayed a marked change along the length of the core. Values were extremely high at the core base, > 70 %, and decreased quite sharply to a low of around 30 % at 55 cm. There was a sharp increase to 50 % loi at 50 cm followed by a dramatic fall to 15 % at 45 cm. Levels remained at around 15 % from 45 cm to 25 cm, above which they rose to 30 % and stabilised at this value to the core top. Carbonate content varied very little from the core bottom to 10 cm with values of around 3 % after which it increased towards the surface to 8 %.

Table 1 **Sediment stratigraphy for KENF2**

Depth (cm)	Sediment type
0-45	Black gytja
45-62	Light brown, dominated by moss remains
62-78	Brown, coarse peat like, dominated by moss remains

Figure 2 **Lithostratigraphic data for KENF2**



3.2 Radiometric analysis

The results of radiometric analyses are given in Appendix table 1 and shown graphically in Figure 3.

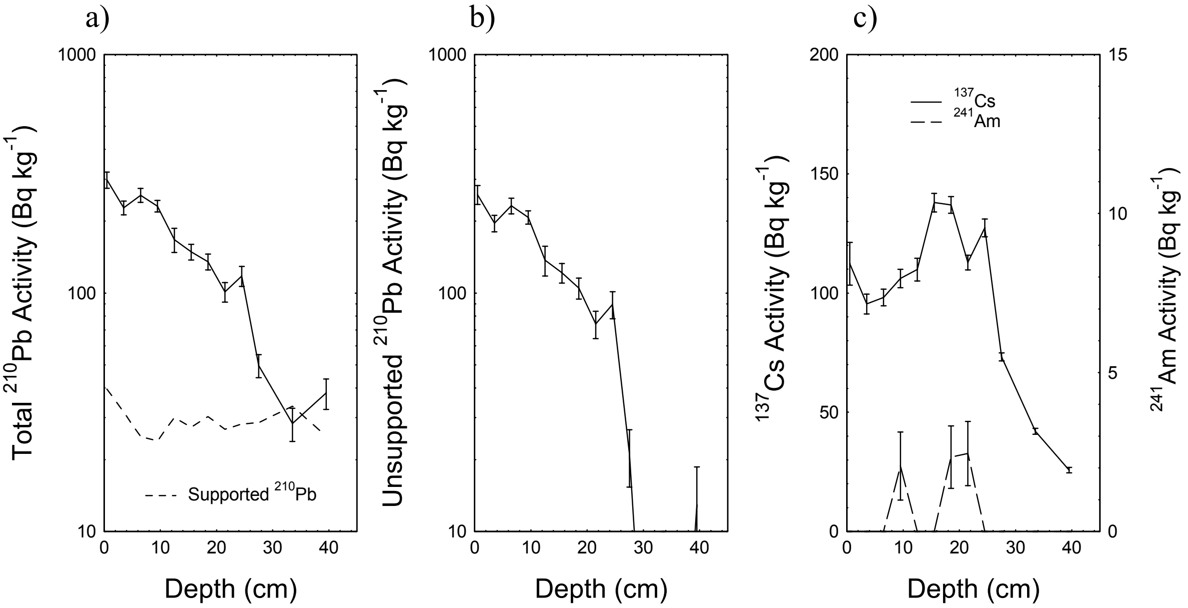
Lead-210 Activity

Total ^{210}Pb activity appears to reaches equilibrium with the supporting ^{226}Ra at a depth of around 30 cm (Figure 3a), though a small excess at 39.5 cm does raise the possibility that the equilibrium at 33.5 cm is due to a dilution event. Unsupported ^{210}Pb activity, calculated by subtracting ^{226}Ra activity from total ^{210}Pb activity, declines more or less exponentially with depth from the surface of the core down to about 24.5 cm. The much steeper decline below this depth could be a further indication of a dilution event, or of a hiatus in the sediment record. The ^{210}Pb inventory of 4630 ± 190 Bq m^{-2} corresponds to a mean ^{210}Pb supply rate of 144 ± 6 Bq m^{-2} y^{-1}. Since this is comparable to the estimated atmospheric flux (and to the value obtained for an earlier 1995 core from this site), if there is a hiatus in the sediment record it is unlikely to have occurred during the past few decades.

Artificial fallout radionuclides

The ^{137}Cs activity versus depth profile (Figure 3c) has a relatively poorly resolved peak between 15-25 cm that almost certainly records the 1963 fallout maximum from the atmospheric testing of nuclear weapons. This interpretation is supported by the presence of traces of ^{241}Am between 19-22 cm.

Figure 3 Fallout radionuclides in Kenfig Pool core KENF2 showing (a) total and supported ^{210}Pb, (b) unsupported ^{210}Pb, (c) ^{137}Cs and ^{241}Am concentrations versus depth.



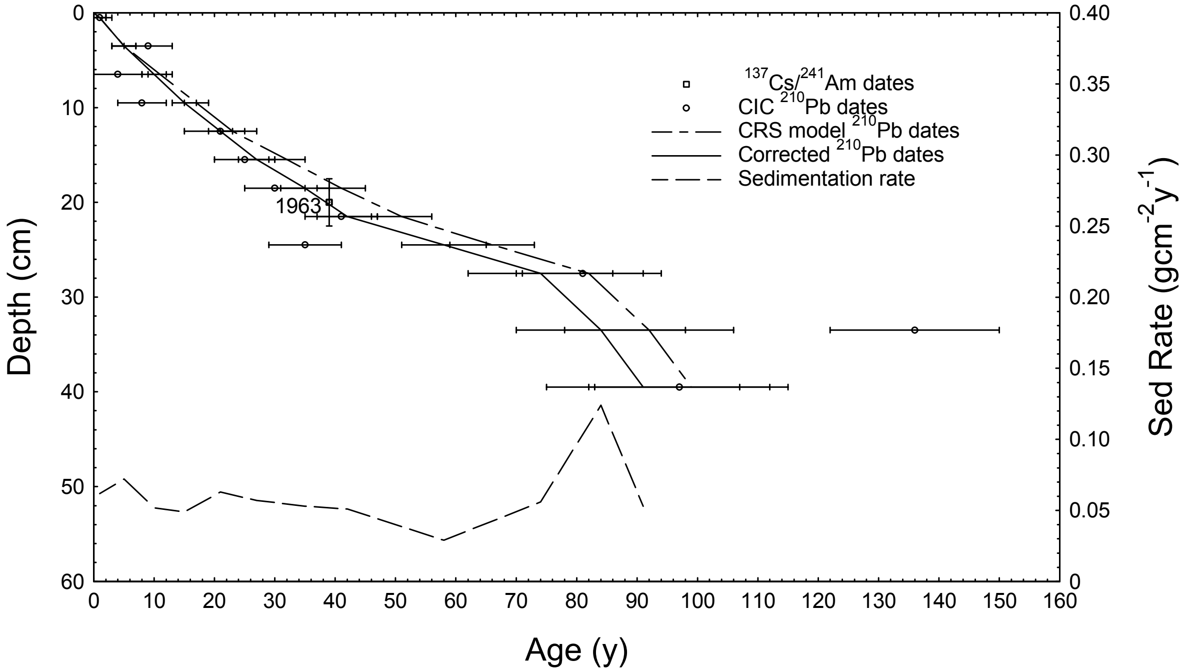
Core chronology

Figure 4 shows ^{210}Pb dates calculated using the CRS and CIC dating models (Appleby *et al.*, 1978), together with the 1963 depth suggested by the ^{137}Cs/^{241}Am record. The CRS model dates place 1963 at a depth of about 17.5 cm, a little above the depth suggested by the ^{137}Cs record. The CIC model dates are a little more irregular but suggest a 1963 depth of about 23.5 cm. The intermediate value of 20.5 cm is consistent with the ^{241}Am record and may provide the best estimate. Revised ^{210}Pb dates have been calculated using this as a reference point. The results, given in detail in Table 2, suggest a brief episode of rapid sedimentation ca. 1918. Dates and sedimentation rates during the early part of the 20th century are however a little speculative and should be regarded with some caution without supporting evidence. Excluding the episode of rapid accumulation, the mean sedimentation rate during the past 70 years is estimated to be 0.046 ± 0.007 g cm^{-2} y^{-1} (0.37 cm y^{-1}). During the past few decades there appears to have been a small but significant acceleration, with a mean sedimentation rate during the past 40 years of 0.057 g cm^{-2} y^{-1} (0.51 cm y^{-1}).

Table 2 ^{210}**Pb chronology of Kenfig Pool core KENF2**

Depth		Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	y	±	g cm^{-2} y^{-1}	cm y^{-1}	± (%)
0.0	0.00	2002	0	0			
0.5	0.04	2001	1	1	0.062	0.70	10.9
3.5	0.31	1997	5	2	0.072	0.67	10.3
6.5	0.62	1992	10	2	0.052	0.60	10.7
9.5	0.90	1987	15	2	0.049	0.55	11.0
12.5	1.19	1981	21	2	0.063	0.50	17.6
15.5	1.61	1975	27	3	0.057	0.43	15.6
18.5	2.00	1967	35	4	0.053	0.40	18.5
21.5	2.39	1960	42	5	0.051	0.26	23.2
24.5	2.85	1944	58	7	0.029	0.19	29.1
27.5	3.38	1928	74	12	0.056	0.35	44.6
33.5	4.64	1918	84	14	0.124	0.67	70.6
36.5	5.36	1915	88	15	0.088	0.35	68.3
39.5	6.08	1911	91	16	0.053	0.22	65.9

Figure 4 **Radiometric chronology of Kenfig Pool core KENF2 showing the CRS and CIC model** ^{210}**Pb dates and the 1963 depth determined from the** ^{137}**Cs/**^{241}**Am record. Also shown are the revised** ^{210}**Pb dates and sedimentation rates calculated using the 1963 date as a reference point.**



3.3 Charophyte stratigraphy

The full results of the macrofossil analysis, both plant and animal remains, can be seen in Appendix Table 2. It was possible to identify four morphologically distinct types of oospore, one *Nitella* species and three *Chara* taxa. Unfortunately, it was not possible to identify the oospores to species level, thus the different types of oospore were assigned a code. It should be noted that the number of oospores present in this core is exceptionally high when compared to other studies (Davidson *et al*., 2002; Bennion *et al*., 2001b).

Charophyte remains showed large changes in abundance over the time period represented by the sediment core, from complete absence in the lowest sample analysed to around 6,300 per 100 cm^3 at 36 cm. A summary diagram of both oospores and selected macro remains is presented in Figure 4. Cluster analysis identified three major zones.

Zone 1 (76-46 cm), with the exception of the bottom sample, was characterised by the presence of at least three of the four discernible types of oospore in numbers in excess of 100 per 100 cm^3. These numbers are low relative to other areas the core but probably indicate a relatively stable community.

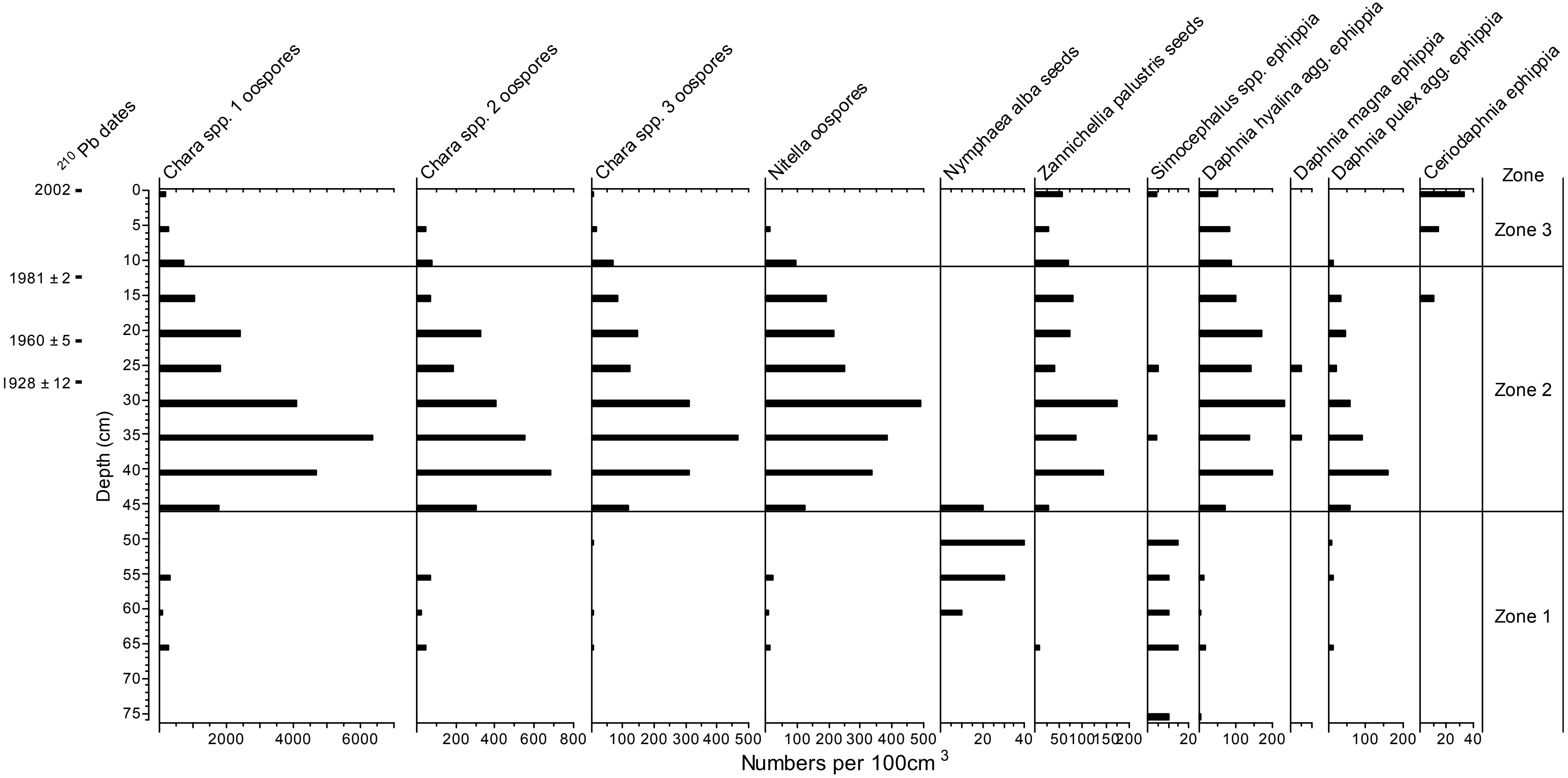
Zone 2 (46-11 cm) was characterised by a dramatic increase in oospore numbers of all four type, overwhelmingly dominated by *Chara* spp. 1, which reached numbers of > 6,000 per 100 cm^3 at 36 cm. The other three types were present in numbers of several 100 per 100 cm^3 throughout this zone. Oospore numbers declined towards the top of zone 2, although abundance remained high and probably reflects a healthy charophyte population.

Zone 3 (11-0 cm) was characterised by a further decline in oospore numbers with the absence of *Chara* spp. 2 and *Nitella* spp. from the surface sediments.

3.4 Plant macrofossil remains

Macrofossil analysis as described by Wasylikowa (1986) and Birks (1980) was not conducted on material from KENF2. Some plant remains were, however, enumerated during the oospore analysis (Figure 5 and Appendix 2). These data are supplemented by further analysis of samples from KENF2 as part of a UCL short course, (Appendix 3), with limitations outlined in the methods section. Nevertheless, the results show a succession of species following the zonations derived from *Characeae* remains. The bottom of the core is characterised by *Myriophyllum spicatum* seeds, *Equisetum* stem remains, moss leaves, *Phragmites* root parts, *Menyanthes trifoliata* seeds and *Nymphaea alba* seeds. At 45 cm there is a dramatic switch to *Zannichellia palustris* seeds and *Ceratophyllum* leaf spines.

Figure 5 **Summary stratigraphy of selected plant macrofossils and cladocera ephippia for KENF2**



3.5 Cladocera stratigraphy

A total of 25 species of Cladocera were recorded from chitinous remains and 5 species or aggregate groups by ephippia. A full list of complete cladocera counts can be seen in Appendix Table 4. Preservation appeared to be good with cladocera concentrations remaining relatively constant down core, with the exception of the 65 cm and 75 cm samples where concentrations were an order of magnitude lower than all other samples.

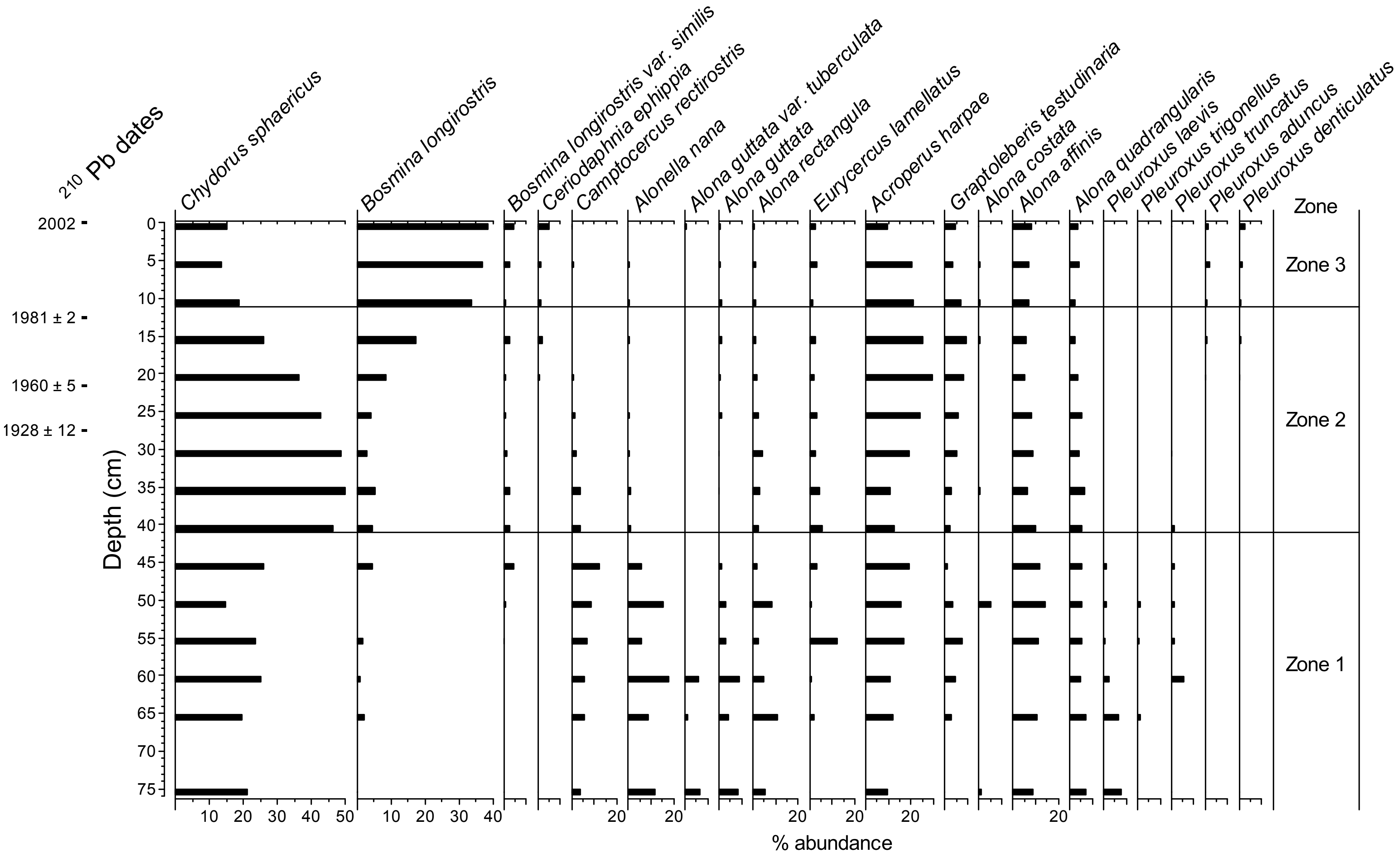
The results of the ephippial remains can be seen in Figure 5 and for chitinous remains in Figure 6. Cluster analysis identified three major zones.

Zone 1 (76-46 cm) was characterised by relatively low numbers of *Daphnia hyalina* agg. and *Daphnia pulex* agg. ephippia and higher number of *Simocephalus* spp. ephippia (Figure 5). The chitinous remains included strongly macrophyte associated species, such as *Pleuroxus laevis, Acroperus harpae, Camptocercus rectirostris* and the low relative abundance of *Bosmina longirostris* (Figure 6). There were also several species present, which tend to be mud associated, such as *Alona guttata, Alona rectangula* and *Alonella nana*. There were subtle changes in the cladoceran assemblage through Zone 1, which may well correspond to several hundred years. There was a slight increase in *B. longirostris,* a decline in *P. laevis* and a shift to *Pleuroxus truncatus*. There was a small rise in the relative abundance of plant associated species: *Eurycercus lamellatus, A. harpae* and *Graptoleberis testudinaria. Chydorus sphaericus* abundance remained relatively constant.

Zone 2 (46-11 cm) was characterised by very high numbers of *Daphnia* ephippia (Figure 5). *D. pulex* abundance peaked at 35 cm and then fell gradually to 10 cm, above which no remains were present. *Daphnia magna* ephippia were present in low numbers in the middle section of the core (25-35 cm) the period of highest Charophyte oospore numbers which probably corresponds to around 1900 AD. *D. hyalina* ephippia numbers peaked between 40 cm and 20cm with levels of 200 ephippia per 100 cm^3. The end of this peak in *D. hyalina* ephippia can be dated to the mid 1960s. Concurrent with the fall in *Daphnia* ephippia was a rise in *Ceriodaphnia* spp. numbers from the 1960s to the present. *Ceriodaphnia* ephippia were recorded in both the macro remain samples and the micro remain samples for this period (Figures 5 & 6). There was a sharp rise in the abundance of *C. sphaericus* at the bottom of the zone. *B. longirostris* increased steadily towards the top of the zone with a concomitant decline in *C. sphaericus* from the peak of 50 % at 35 cm. There was a reduction in the proportion of benthic species such as *Alonella nana, Alona rectangula* and epiphytic species, with the exception of *A. harpae* and *G. testudinaria*. The large increases in *Daphnia* spp. ephippia in this zone (Figure 5) probably correspond to the late 19th, early 20th century. This period in the lake's history appears to have seen a shift to planktonic (*Daphnia)* and semi-planktonic (*C. sphaericus*) species.

Zone 3 (11-0 cm) was characterised by the increased dominance of *B. longirostris*, a small planktonic cladoceran and an increase in the proportion of *B. longirostris var.* similis (Figure 6). The relative abundance of *C. sphaericus* fell and there was switch in the *Pleuroxus* species to *P. aduncus* and *P. denticulatus*. The proportions of species, such as, *A. harpae, G. testudinaria, Eurycercus lamellatus*, *Alona affinis* and *Alona quadrangularis* were relatively constant.

Figure 6 **Cladocera stratigraphy of selected chitinous and ephippial fossils for KENF2**



There were also changes in the ephippial remains (Figure 5), notably of the *Daphnia* taxa, only *D. hyalina* occurred albeit in reduced numbers. There was and an increase in the number of ephippia of the smaller planktonic species of *Ceriodaphnia*.

3.6 Comparison with 1995 ecological survey

Based on the radiometric dating results, the sample that corresponds most closely to the ecological survey of 1995 is the 5-6 cm sample. Three morphologically distinct *Chara* oospores and one *Nitella* oospores were present in the sediment sample, whereas only one *Chara* oospores and one *Nitella* species were recorded in the survey in 1995 (ENSIS, 1996). There are also some discrepancies between the survey of modern cladocera from 1995 and the sedimentary remains from the sample closest to that time. Sedimentary fossil remains may well represent not only a whole growing season, but an accumulation of material from a number of years. Furthermore, the survey in July 1995 was a mid summer 'snapshot' of macrophyte and cladoceran populations, certain species of both community types may display some seasonality in presence and absence. Given the errors associated with dating (+/- 2 years), it is possible the 5-6 cm may not represent the year of 1995. It is not surprising, therefore, that there are differences between the fossil and modern data sets. Discrepancies may be compounded by taphonomic problems outlined in the methods section.

4 Discussion

4.1 Dating and sediment accumulation rates

The ^{210}Pb and ^{137}Cs chronology for KENF2 for the last century appears to be reliable, showing a small but significant rise in accumulation rates in the last 20 years. This may be due to increased autochthonous or allochthonous material production. The increase in % loi and decrease in % dry weight are, however, more indicative of an increase in within lake production.

Figure 1 and Table 2 show dramatic changes in the lithostratigraphic characteristics of the sediments over the time period represented by KENF2. Thus, a uniform sedimentation rate cannot be assumed, making extrapolation of dates for the lower parts of the core unreliable. Additionally, there is often considerable compaction of sediments in the lower levels of cores due to the weight of material above, causing further problems for a linear extrapolation of dates. For these reasons precise dates cannot be ascribed to the lower levels, and our best estimate is that the core represents at least 300 or 400 years.

4.2 Environmental trends at Kenfig Pool

The environmental history of Kenfig Pool can be divided into three distinct periods: Zone 1, from approximately 76-46 cm; Zone 2 from around 46-15 cm and Zone 3 from roughly 15-0 cm. The palaeolimnological data presented here; sediment lithostratigraphy, oospores abundance and cladoceran assemblages, all respond in concert, with distinct values and assemblages characteristic of each zone. Cluster analysis based on the different types of fossil produced almost exactly the same stratigraphical zones. Thus, in discussing the environmental history of Kenfig pool it was decided not to separate the different indicators.

Oligotrophic, shallow lake

Zone 1 has the flora and fauna of an oligotrophic shallow lake. The oospores record indicates a relatively low abundance of stoneworts, the more complete macrofossil record (Appendices 2 & 3) indicates the presence of *Menyanthes trifoliata, Myriophyllum spicatum* and *Nymphaea alba* and abundant aquatic mosses. Although oospore numbers were low in this period compared to the upper zones, they were still relatively high in comparison with other studies (Davidson *et al*., 2002, Bennion *et al*., 2001, Oodgaard, 1997), and were sufficient in number to indicate a healthy community (Zhao *et al*., 2001). It should also be noted that some of the plant remains are indicative of relatively shallow water, such as *Phragmites* roots, *M. trifoliata* and *Equisetum* stem material. The abundance and composition of the cladocera fossils, many of which are benthic species (*Alonella nana, Alona guttata)* along with the plant macrofossils, indicate a system of low growing plants mixed with areas of bare sediment. The relatively high abundance of obligate epiphytic cladoceran species (*Simocephalus* spp., *Camptocercus rectirostris* and *Pleuroxus laevis*) may indicate the lack of phytoplankton as a food source. The cladoceran community in this period was very even, with no single species dominating the assemblage.

There is little documentary data on the fish community at this time. Giles (2002) state that the natural fish community of Kenfig Pool would consist of sticklebacks (*Pungitius pungitius*) and eels (*Anguila anguila*). Rudd (*Scardinius erythropthalamus*), pike (*Esox lucius*) and perch (*Perca fluviatilis*) occur naturally in this area (Maitland, 2002) but they are thought not to have been able to naturally colonise the site (Giles, 2002). One historical record of the fish community by Ward (1931) notes that in 1570 the Earl of Pembroke litigated against Sir Edward Mansell in defence of the valuable fishery at Kenfig. The species, however, were not stated, but eels from the pool and salmonids *Salmo salar, Salmo trutta* from the river Kenfig were mentioned. Ward also states that in Hansard's time (c. 1830) the lake held perch (*Perca fluviatilis)* and that water lilies were abundant on the western shore. The presence of the latter is recorded in the macrofossil profile by *N. alba* seeds in this section of the core.

Characeae and planktonic cladoceran dominance

Zone 2 shows a dramatic increase in the abundance of *Characeae* oospores to extremely high levels, indicating the presence of large beds of different *Chara* and *Nitella* species. There is a synchronous shift in the cladocera community away from the benthic and epiphytic species to planktonic species, (at least three species of large bodied *Daphnia*) and semi-planktonic species, *Chydorus sphaericus*.

It is difficult to definitively attribute the shift in communities to one cause. If the last reliable accumulation rate is extrapolated, the change can be dated to around 1850. The profusion of stonewort growth in this period may have been the result of nutrient enrichment of the pool. More nutrients would be available for plant growth and the development of phytoplankton, in turn providing sufficient food to the efficient feeding *Daphnia* species. The biological changes are coincidental with a large reduction in % loi, not usually indicative of nutrient enrichment. The shift in submerged plant and cladocera community may also have been due to changes in water level or lake morphology, increasing the area available for colonisation by aquatic plants. The presence of emergent species in Zone 1 and their absence from Zone 2 may indicate a shift in water level and a change from littoral to more open water species. Orr (1912), however, states that the lake was approximately the same size in 1876 as it is at present but that "it was of less extent and slightly different outline to the pool of 1814". Thus, it seems the pool had decreased in size over the period where the transition in biological occurred. Orr (1912) also states that the pool was originally a marsh, but does not state when.

The macrophyte flora, *M. spicatum* & *N. alba,* from the base if the core indicates that the site of the core has been a lake for the length of the core.

In shallow lakes, fish (Brooks & Dodson, 1965) and plants (Jeppesen *et al.*, 1998, Ogden, 2000) play key roles in structuring the cladoceran abundance and species composition. An increase in the size of the plant beds as indicated by the macrofossil record of Kenfig Pool would result in a reduction of open water and therefore an increase in the proportion of obligate epiphyte species such as *Simocephalus* spp. and *Pleuroxus* spp. (Lauridsen *et al.*, 1996). The latter was not observed, however, in the fossil cladocera record. A possible explanation for this observation is that in the absence of fish the prevalence of macroinvertebrate predators may control the plant-associated cladocerans and result in the increased numbers of large *Daphnids*. These large *Daphnids* and increased proportion of *C. sphaericus* may indicate an increase in lake productivity. Further evidence of enrichment is provided by the presence of the more nutrient tolerant plant species *Zannichellia palustris* and *Ceratophyllum spp.* in the macrofossil record at this time. It is, however, very difficult to pinpoint the cause of the observed ecological shifts, and a combination of increased nutrient availability and water level change may be responsible.

Decline in Characeae and Daphnia abundance

The next period to consider is that dated from approximately 1930 AD (c. 25-30 cm) of the core to which consists of parts of zone 2 and 3. The sedimentary remains of all the plant and animal remains indicate declining ecological quality of the Pool. Charophytes oospore abundance decreased markedly and *Daphnia* ephippia numbers declined, the larger bodied *D. pulex* disappearing completely. A switch from large bodied planktonic cladocera to smaller less efficient feeding species (*Bosmina longirostris* and *Ceriodaphnia* spp.) occurred. These shifts reflect the classic cladoceran community structure response to an increase in fish predation pressure found in a number of studies from different lake types (Hrbácek *et al.*, 1961; Brooks & Dodson, 1965; Kitchell & Kitchell, 1980; Jeppesen *et al.*, 1996; Jeppesen *et al.*, 2001). Brooks & Dodson (1965) demonstrated that the introduction of zooplanktivorous fish, the *Alosa* or 'ale wife', resulted in a shift from the dominance of large bodied *Daphnia* spp. to smaller bodied species, such as, *Bosmina longirostris*. The study led to the development of the 'size efficiency' hypothesis, which states that fish will select the largest prey possible, thus, in the presence of fish, smaller bodied cladocera species and smaller individuals of a particular species have a competitive advantage.

There is historical data for fish in Kenfig pool at this time with the presence of perch, pike, eels, roach (*Rutilus rutilus*) and rudd noted for the early part of this century (Giles, 2003). There is also a well documented history of fish stocking events from the 1950s onwards. Appendix 5 shows fairly constant and at times inappropriate (particularly brown and rainbow trout and carp) fish stocking with the first stocking event occurring in 1957. Fish effects are known to cascade down the trophic levels of shallow lakes affecting phytoplankton biomass, macrophyte abundance and even nutrient availability (Carpenter *et al.*, 1985; Carpenter & Lodge, 1986; Jeppesen *et al.*, 2001). It seems likely that the fish stocking practiced over the last century has had a dramatic effect on, not only the zooplankton population, but also the abundance and composition of submerged plants.

Contemporary reduction in fish abundance

The final section of the core, from around 10 cm to the top, representing approximately the last 15 years shows a further change in the cladocera community. The relative abundance of *B. longirostris* was high in this zone, the absolute abundance, however, (numbers g^{-1} wet weight, Appendix 6) decreased at the top of the core. There was also an increase in the abundance of *Ceriodaphnia* ephippia. This shift from the small bodied *Bosmina* to the large *Ceriodaphnia* should, according to the size efficiency hypothesis, occur if there was a reduction in the fish predation pressure. The recent fish survey of Kenfig Pool undertaken in spring 2003 (Giles, 2003), revealed a very low fish density, which would explain the changes observed in the cladocera record. Giles (2003) attribute the low density of fish to cormorant predation, the effects of which appear to be cascading down the trophic levels, and impacting on the cladocera community. There was not, however, any reversal in the decline in oospore diversity and abundance. There may be a lag in the recovery of *Characeae*, or there may have been a more permanent shift to a macrophyte community dominated by more nutrient tolerant species.

Reference conditions for Kenfig Pool

The Water Framework Directive requires that reference conditions, corresponding to a pristine or near pristine, are established for all types of lakes. These reference conditions may then be used as a point of reference against which any change can be assessed. Of the three distinct biological communities determined by the analysis of sedimentary remains there seems little doubt that the bottom of the core equates most closely to populations that could be described as pristine. The fish community according with reference conditions for Kenfig Pool are more difficult to ascertain. Giles (2003) suggest the ‘natural’ community would have consisted of sticklebacks and eels, (perch also have a long history at the site). To restore the site to this state would almost certainly require a reduction in nutrient levels and some manipulation of the fish community dramatically reducing the current value of the site as a fishery resource.

The period of dominance by Characeae may be a more appropriate aim for any management strategy. It could not, however, be classed with certainty as the reference condition. This stage having perhaps resulted from some human interference either indirect, e.g. nutrient enrichment, or direct manipulation of fish stocks, perch were recorded from around 1830 (Ward, 1931), there may also have been water level changes. Additionally, nutrient tolerant species of macrophytes, *Z. palustris* and *C. demersum* were present. The fish community from this period is again uncertain, containing at least perch in addition to the species already present. It would, thus, have been dominated by piscivorous fish, perch and eel, with an unknown contribution from the largely zooplanktivorous stickleback.

5 Summary

Kenfig Pool is an important site, both in terms of nature conservation and as a valued fishery resource. The analysis of Charophyte oospores and cladocera remains revealed that the site has been through a series of apparently dramatic and more gradual changes over the last few hundred years. Most relevant here are the changes in ecology that have occurred during the last one hundred years, the period for which there is both a good chronology of the sediment samples and detailed records of fish stocking events. The sedimentary *Characeae* oospore profile for the last century suggests that there has been a reduction in the conservation value of Kenfig Pool, in terms of its submerged vegetation. This decline occurs in tandem with changes in the cladoceran community which are indicative of an increase in fish predation pressure, the records of fish stocking for this period supporting this hypothesis. Thus, the data strongly suggest that top down ‘fish effects’ have cascaded through the trophic levels affecting the submerged flora of the site. The exact mechanism for this could not be determined form the sediment record, it is likely, however to have been due to a reduction in the quality of the light climate. Recent changes in the cladoceran assemblages in the uppermost sections of the core are indicative of a recent reduction in fish predation pressure and appear to be due to the high level of cormorant predation observed at the Pool (Giles, 2003). Whilst the cladoceran community reflects a decline in fish predation pressure, the sediment record provided no evidence of this reduction halting the apparent decline of the charophyte community.

6 Recommendations

The study strongly suggests that the fish stocking practices over the last 55 years have played a large part in the decline in the conservation value of Kenfig Pool. This does not mean that a fishless site is desirable, however, an appropriate fish community is essential if a diverse and valuable aquatic flora is to be maintained. Giles (2003) recommends a self sustaining fish community of perch, pike, eels, rudd and tench (*Tinca tinca*) for Kenfig pool, of these species only tench would not occur naturally in the region (Maitland, 2002). This is an artefact of the species' post-glacial distribution rather than a function of it appositeness in a macrophyte dominated shallow lake. Indeed, clear water lakes tend to have fish communities dominated by tench and rudd (Perrow *et al.*, 1997). The aim should be to have a fish community dominated by large individuals. This is desirable for both anglers and the conservation value of the site. The dominance of the biomass by large fish, with piscivores such as pike, large perch and eels would ensure that the population of small fish was kept in check, allowing the development of an abundant population of large bodied cladocerans. This in turn would keep the phytoplankton population in check and hence maintain a good light climate for submerged plant growth.

The relatively low nutrient levels of Kenfig Pool may preclude a switch to a phytoplankton dominated state. To maintain the conservation value of the site, however, caution needs to be exercised in the implementation of any further fish stocking. The long life span of fish mean any stocking event will have an effect for many years to come, the stocking of carp in 1987 providing a good illustration of this point. It is vitally important that a healthy population of piscivorous fish are present. The maintenance of both littoral (pike) and more open water (large perch) piscivores is important in controlling populations of small zooplanktivorous fish (Søndegaard *et al*., 1997; Perrow *et al*., 1999; Jeppesen & Sammalkorpi, 2001). The overall recommendations of recent fishery management plan by Giles & Associates (2003) appear sensible, particularly:

- The long term objective of attaining a self-sustaining fishery of pike, perch, rudd, tench, and eels.
- A ban on the introduction of any new fish species, particularly benthivorous species, such as carp, or species with no potential to self-sustain (brown trout).
- Removal of carp.
- Monitoring for any indication of eutrophication.

Conditional on removal of carp, the clearing out of the lagoon to encourage tench spawning, recommended by Giles (2003) could only have benefits for the conservation value of the site adding to habitat diversity and hopefully creating the conditions for a self sustaining fishery.

Recommendations for future management are

- Monitoring programme for aquatic macrophytes, cladocera and fish as part of any ongoing site management plan.
- Perch should not be removed as was recommended in the draft report by Giles (2003), perch can be are important in the maintenance of clear water as their predation on small fish is often more voracious than that of pike (Jeppesen & Sammalkorpi, 2001).
- The removal of piscivores, such as eels, should be approached with caution. Piscivores are of key importance to maintaining a low abundance of small, chiefly zooplanktivorous, rudd.

The recommendation for building timber reefs to protect fish from winter cormorant predation is an interesting one as the provision of such structures may influence the structure of the fish community. Increased littoral like refuge decreases the incidence of cannibalism in pike (Grimm & Backx, 1990) possibly resulting in more effective predation on zooplanktivorous fish. Young perch may also be given a competitive advantage, given their preference for a structured habitat in which to forage for invertebrate prey. Thus, the effects of placing artificial refugia in the lake will not have a simple one component effect on the food web structure and their impact should be monitored. The effects mentioned however will all increase the likelihood of a piscivore dominated site.

A final recommendation is that the management of the site should be reviewed on a regular basis, perhaps every five years. If the current recommendations are applied then their affects need to be monitored and reviewed in the light of new information. Responsible anglers can provide vital information, such as the presence of large tench, their apparent spawning success and should active involvement in site management should be encouraged wherever possible.

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9 Appendices

9.1 Fallout radionuclide concentrations in Kenfig Pool core KENF2

Depth		^{210}Pb Total		^{210}Pb Unsupported		^{210}Pb Supported		^{137}Cs	
cm	g cm^{-2}	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±
0.5	0.04	298.2	23.0	258.7	23.5	39.6	5.2	112.3	9.0
3.5	0.31	227.9	15.1	196.2	15.5	31.7	3.3	95.4	4.2
6.5	0.62	257.1	17.3	232.1	17.4	25.0	2.4	98.2	3.5
9.5	0.90	231.5	12.9	207.6	13.1	24.0	2.3	106.1	3.9
12.5	1.19	167.4	19.3	137.4	19.7	30.0	3.6	109.8	4.7
15.5	1.61	148.8	11.1	121.4	11.4	27.4	2.6	137.9	3.9
18.5	2.00	135.3	10.4	104.9	10.7	30.3	2.3	137.0	3.5
21.5	2.39	101.0	9.5	74.2	9.7	26.8	2.2	112.8	3.1
24.5	2.85	117.9	11.4	89.7	11.7	28.2	2.7	127.3	3.7
27.5	3.38	49.6	5.5	21.0	5.7	28.6	1.3	73.2	1.7
33.5	4.64	28.4	4.5	-5.1	4.7	33.5	1.3	42.0	1.3
39.5	6.08	38.0	5.6	12.9	5.7	25.1	1.3	25.7	1.2

9.2 Macrofossil remains data for KENF2. Data expressed as numbers per 100 cm^3

	Sample depth in cm														
Remain	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**75**
Ceriodaphnia ephippia	33	14	0	11	0	0	0	0	0	0	0	0	0	0	0
Chara species 1 oospores	210	276	750	1068	2400	1825	4094	6357	4680	1785	25	345	100	270	0
Chara species 2 oospores	0	48	75	68	325	190	406	552	685	305	0	70	25	45	0
Chara species 3 oospores	5	14	70	84	145	125	313	467	310	120	5	0	5	5	0
Chara species 4 oospores	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Cristatella mucedo statoblast	14	38	25	47	35	0	19	29	25	10	0	0	0	0	0
Daphnia hyalina agg. ephippia	48	81	85	100	170	140	231	138	200	70	0	10	5	15	5
Daphnia magna agg. ephippia	0	0	0	0	0	5	0	5	0	0	0	0	0	0	0
Daphnia pulex agg. ephippia	0	0	10	32	45	20	56	90	160	55	5	10	0	10	0
Menyanthes trifoliate seed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Moss leaves	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Nitella oospores	0	14	95	189	215	250	494	386	335	125	0	20	5	10	0
Nymphaea alba seeds	0	0	0	0	0	0	0	0	0	20	40	30	10	0	0
Potamogeton seed	0	0	0	0	0	0	0	0	0	5	0	5	0	0	0
Ranunculus batrichium sect. seed	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
Simocephalus ephippia	5	0	0	0	0	5	0	5	0	0	15	10	10	15	10
Zannichellia palustris seed	57	29	70	79	75	40	175	86	145	30	0	0	0	10	0

9.3 Selected plant macrofossil remains data for KENF2 derived from the in-house UCL training course.

Data are expressed as numbers per 100 cm^3

	Sample Depth in cm																
Remain	**2.5**	**7.5**	**11.5**	**16.5**	**17.5**	**18.5**	**20.5**	**22.5**	**31.5**	**38.5**	**46.5**	**54.5**	**57.5**	**62.5**	**65.5**	**71.5**	**75.5**
Chara oospores	44	99	512	461	500	600	210	895	919	500	137	150	2	207	288	0	7
Moss leaves	25	0	6	0	50	100	198	28	166	500	500	284	500	200	72	0	0
Zannichellia palustris seed	23	0	60	28	40	30	18	33	72	44	31	23	0	5	0	0	0
Ceratophyllum spines	23	0	2	0	2	3	6	0	3	18	5	0	0	0	0	0	0
Phragmites roots	0	0	0	0	0	0	0	0	0	0	0	0	200	0	500	200	0
Menyanthes trifoliata seeds	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4	0
Equisetum stem	0	0	0	0	0	0	0	0	0	0	0	0	200	0	0	200	0
Myriophyllum spicatum seeds	0	0	0	0	0	0	0	0	0	0	0	0	48	3	0	0	0
Nymphaea alba seeds	0	0	22	0	0	0	15	0	0	4	153	35	6	0	0	0	13

9.4 Cladoceran data for KENF2. Data are expressed as % relative abundance

	Sample depth in cm														
Species	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**75**
Acroperus harpae	9.2	20.5	21.0	25.4	29.3	24.1	18.9	10.6	12.4	19.0	15.3	16.6	10.7	12.0	9.3
Alona affinis	8.3	7.1	7.1	5.9	5.3	8.2	8.9	6.3	10.0	12.0	13.9	11.2	0.0	10.7	8.7
Alona costata	0.0	0.2	0.5	0.6	0.0	0.0	0.0	0.6	0.0	0.0	5.2	0.0	0.0	0.0	1.2
Alona guttata var. tuberculata	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.3	6.4
Alona guttata	0.4	0.6	1.0	1.5	0.7	1.1	0.3	0.3	0.0	1.1	3.1	3.3	9.0	4.0	8.7
Alonella nana	0.0	0.4	0.5	0.6	0.0	0.3	0.3	1.1	0.8	5.8	15.3	5.7	17.9	8.7	11.6
Alona quadrangularis	3.7	4.3	2.1	2.4	3.4	5.2	4.4	6.9	5.4	5.5	5.2	5.2	4.7	7.3	7.0
Alona rectangular	0.9	1.5	1.2	1.2	1.7	2.2	4.2	3.2	2.7	1.8	8.7	2.5	4.7	10.7	5.2
Alona rustica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
Alonella excisa	1.5	0.4	0.2	0.6	0.5	0.5	0.6	0.6	0.0	0.0	0.3	0.5	1.3	2.0	0.0
Bosmina longirostris	38.6	37.1	33.8	17.4	8.7	4.1	2.8	5.4	4.6	4.7	0.0	1.9	0.9	2.0	0.0
Bosmina longirostris var. similis	4.4	2.4	1.0	2.4	0.7	0.5	1.1	2.3	2.7	4.0	0.7	0.3	0.0	0.0	0.0
Camptocercus rectirostris	0.2	0.6	0.0	0.0	0.7	1.1	2.2	3.7	3.5	12.4	8.4	6.8	5.6	5.3	3.5
Chydorus sphaericus	15.0	13.4	18.8	26.0	36.1	42.5	48.6	49.9	46.3	25.9	14.6	23.4	25.2	19.3	20.9
Eurycercus lamellatus	2.4	3.0	1.2	2.7	1.9	3.6	2.5	4.6	5.4	3.3	1.0	12.3	0.9	2.0	0.0
Graptoleberis testudinaria	4.6	3.2	6.9	9.4	8.0	6.0	5.0	2.9	2.3	1.1	3.5	7.4	4.3	2.7	0.0
Monospilus dispar	0.2	0.0	0.5	0.0	0.9	0.0	0.0	1.7	1.5	0.4	1.0	0.0	0.0	0.7	0.0
Pleuroxus aduncus	1.1	1.9	0.7	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuroxus denticulatus	2.8	1.3	0.7	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuroxus spp.	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuroxus laevis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.0	0.8	2.6	6.7	8.1
Pleuroxus trigonellus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.8	0.0	1.3	0.0
Pleuroxus truncates	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.5	1.5	1.4	1.4	5.6	0.0	0.0
Pleuroxus uncinatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Rhynchotalona falcata	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tretocephala ambigua	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Bosmina longirostris ephippia	1.5	0.4	1.4	1.2	0.5	0.3	0.0	0.0	0.8	0.0	0.0	0.0	0.0	1.3	0.0
Ceriodaphnia spp. ephippia	4.8	1.5	1.4	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

9.5 Known recent fish stocking at Kenfig Pool

Species	Date	Number / Weight	Notes
Mixed coarse fish	1957	3,000	1
Rainbow trout	1962	250	1
Rainbow trout	1963	500	1
Brown trout	1964	250	1
Rainbow trout	1964	250	1
Brown trout (fry)	1968	500	1
Brown trout	1968	250	1
Brown trout	1973	200	1
Perch	1981	750	1
Perch	1982	550	1
Carp	1987	300 lb	1
Rainbow trout	1988	650	1
Brown trout	1989	300	1
Rainbow trout	1991	1,000	1
Tench	1992	2,000	1
Rudd	1993	2,000	1

Notes: NCC/CCW consented all stocking from 1987. NCC/CCW also consented the stocking of pike (1987, 1991, 1992), Key to sources: 1 = EA undated, from KHDAA records, see also Favager, 1998.

9.6 Cladoceran data for KENF2. Data are expressed as numbers g^{-1}

	Depth in cm														
Species	**0-1**	**5-6**	**10-11**	**15-16**	**20-21**	**25-26**	**30-31**	**35-36**	**40-41**	**45-46**	**50-51**	**55-56**	**60-61**	**65-66**	**75-76**
Acroperus harpae	37.3	112.9	246.1	234.1	330.0	145.4	236.0	74.6	92.4	115.9	155.1	259.4	45.4	22.7	25.5
Alona affinis	33.6	39.2	83.9	54.4	59.8	49.6	111.0	44.3	75.0	73.5	141.0	174.4	0.0	20.2	23.9
Alona costata	0.0	1.2	5.6	5.4	0.0	0.0	0.0	4.0	0.0	0.0	52.9	0.0	0.0	0.0	3.2
Alona guttata var. tuberculata	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.4	2.5	17.5
Alona guttata	1.5	3.6	11.2	13.6	7.7	6.6	3.5	2.0	0.0	6.7	31.7	51.0	38.2	7.6	23.9
Alonella nana	0.0	2.4	5.6	5.4	0.0	1.7	3.5	8.1	5.8	35.6	155.1	89.3	76.3	16.4	31.8
Alona quadrangularis	14.9	23.8	25.2	21.8	38.6	31.4	55.5	48.4	40.4	33.4	52.9	80.8	20.0	13.9	19.1
Alona rectangular	3.7	8.3	14.0	10.9	19.3	13.2	52.1	22.2	20.2	11.1	88.1	38.3	20.0	20.2	14.3
Alona rustica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.1
Alonella excisa	6.0	2.4	2.8	5.4	5.8	3.3	6.9	4.0	0.0	0.0	3.5	8.5	5.5	3.8	0.0
Bosmina longirostris	156.0	204.4	397.2	160.6	98.4	24.8	34.7	38.3	34.6	29.0	0.0	29.8	3.6	3.8	0.0
Bosmina longirostris var. similis	17.9	13.1	11.2	21.8	7.7	3.3	13.9	16.1	20.2	24.5	7.1	4.3	0.0	0.0	0.0
Camptocercus rectirostris	0.7	3.6	0.0	0.0	7.7	6.6	27.8	26.2	26.0	75.8	84.6	106.3	23.6	10.1	9.5
Chydorus sphaericus	60.5	73.7	221.0	239.6	407.2	256.1	607.3	350.6	346.3	158.2	148.1	365.8	107.2	36.6	57.3
Eurycercus lamellatus	9.7	16.6	14.0	24.5	21.2	21.5	31.2	32.2	40.4	20.1	10.6	191.4	3.6	3.8	0.0
Graptoleberis testudinaria	18.7	17.8	81.1	87.1	90.7	36.3	62.5	20.2	17.3	6.7	35.3	114.8	18.2	5.1	0.0
Pleuroxus aduncus	4.5	10.7	8.4	5.4	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuroxus denticulatus	11.2	7.1	8.4	5.4	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuroxus spp.	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuroxus laevis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	10.6	12.8	10.9	12.6	22.3
Pleuroxus trigonellus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	12.8	0.0	2.5	0.0
Pleuroxus truncates	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	11.5	8.9	14.1	21.3	23.6	0.0	0.0
Pleuroxus uncinatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Ceriodaphnia spp. ephippia	19.4	8.3	16.8	16.3	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0