Research Papers

No. 24

PALAEOECOLOGICAL EVALUATION OF THE RECENT ACIDIFICATION OF WELSH LAKES

8. Eiddew Bach, Gwynedd

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Palaeoecological Evaluation of the Recent Acidification of Welsh Lakes.

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Summary

i) Core studies of diatoms, pollen, chemistry, carbonaceous particles and magnetics together with a land use study have been conducted at Eiddew Bach, Gwynedd. An upland oligotrophic lake situated on the west side of the Rhinog plateau.

ii) The $^{210}$Pb inventory is very low and there is evidence that sediment from the last two decades or so is missing from the top of the core. The top 2 - 3 cm represent sediment accumulated between the 1950's and 1960's.

iii) The diatom based pH reconstructions suggest that the pH of Eiddew Bach was 6.7 - 6.9 throughout the basal 10 cm of analysed sediment. From 8 cm a number of acidophilous taxa and undesignated Navicula species appear and increase in abundance, including Navicula heimansii, N. melicrista, N. indifferentens, N. tenuicepsa and Navicula maduensisia. From 2 cm the most marked change occurs indicating incipient acidification as the planktonic Cyclotella kutzinghiana and the alkaliophilous Fragilaria construens var. venter decline and acidophilous taxa like Navicula hassica increase.

iv) The core chemistry record demonstrates that trace metal contamination by lead and zinc of the lake sediments began at 7.5 cm.

v) The contamination of the sediments by carbonaceous particles commences at 9 cm. The concentration of these particles increase rapidly from 3 cm. A similar trend is shown by the magnetic data.

vi) The recent portion of the pollen diagram indicates that little change has occurred in the catchment vegetation over the last 150 years. The pollen diagram also reveals a major hiatus in the core at 20 cm below which sediments dating to approximately the elm decline 'ca. 5000 B.P.' occur.

vii) No appreciable land use change has occurred within the catchment. While sheep numbers have increased in the area in recent years the documentary evidence is not precise enough to assess whether the catchment has experienced a significant increase in grazing pressure. No liming has taken place within the catchment and burning has not been a significant management practice.

viii) Since recent sediment is missing from the top of the core it is not possible to present a complete picture of changing pH through time. However, a substantial acidification of the lake has occurred over the last 50 years or so. High concentrations of carbonaceous particles in lakes have only occurred since the 1930's. On this basis the uppermost 2 cm of the core clearly postdates 1930 and contains a diatom assemblage indicative of pH values > 6.0. Since the present pH is about 4.5 a pH decline of approximately 1.5 units must have occurred over the last few decades. Since no significant catchment changes have taken place during this period we must conclude as for other sites in the areas, that the acidification has been caused by acid deposition.
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## Explanation of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAS</td>
<td>Agricultural and Development Advisory Service.</td>
</tr>
<tr>
<td>MAFF</td>
<td>Ministry of Agriculture, Fisheries and Food.</td>
</tr>
<tr>
<td>NCC</td>
<td>Nature Conservancy Council.</td>
</tr>
<tr>
<td>NLW</td>
<td>National Library of Wales.</td>
</tr>
<tr>
<td>PAH</td>
<td>Polyaromatic Hydrocarbons.</td>
</tr>
<tr>
<td>PRO</td>
<td>Public Record Office.</td>
</tr>
<tr>
<td>WWA</td>
<td>Welsh Water Authority.</td>
</tr>
<tr>
<td>SSSI</td>
<td>Site of Special Scientific Interest.</td>
</tr>
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<td>UCNW</td>
<td>University College North Wales.</td>
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</table>
1.0 Introduction

Surface water acidification is recognised as one of the most important environmental problems in Europe and North America, yet despite the pioneering work of Gorham on precipitation chemistry in Cumbria (Gorham 1958) the extent of acidification in the UK is still not known. In earlier papers (Flower and Battarbee 1983, Battarbee et al. 1985, Jones et al. 1986, Flower et al. 1987) we established that lakes on granitic rocks in Galloway, South West Scotland, were strongly acidified and that the most likely cause of the acidification was acid deposition. We have now extended our enquiry to acid lakes in Wales and other parts of Scotland to test the general hypothesis that clearwater lakes with pH values less than 5.5, occurring within areas of high acid deposition, are acidified due to an increase in acid deposition over recent decades.

Eiddew Bach located on the west side of the Rhinog plateau, Gwynedd, was the fifth site (Fig. 1) to be chosen in Wales. While there are no site records of acid deposition, records from nearby Aberystwyth reveal that the mean pH of precipitation is ca. 4.5 and the annual wet sulphate loading is 1.2 - 1.6 g m\(^{-2}\) yr\(^{-1}\) (Figs. 2 & 3). The catchment is largely undisturbed, comprising upland moorland and rough grazing for sheep. Sediment cores were obtained in August 1985.

Our approach involves the use of diatom analysis to reconstruct past pH values; \(^{210}\)Pb analysis to establish a lake sediment chronology; geochemical, magnetic and "soot" analysis to trace the history of atmospheric contamination; and pollen analysis and land-use history studies to evaluate the influence of catchment changes on the past ecology of the lake.
1. Eiddew Bach location map
2. Average annual rainfall weighted hydrogen ion concentration deposition for the U.K. (Redrawn from Barrett et al 1983)

3. Average annual deposition of non-marine sulphate for the U.K. (Redrawn from Barrett et al 1983)
2.0 Site details

2.1 Lake

The lake lies at an altitude of 380 m in an area which receives a rainfall of 2000 mm yr\(^{-1}\). It is a narrow body of water (surface area 13,771 km\(^2\)), which drains a small catchment of 109,396 m\(^2\). The detailed bathymetry (Fig. 4) reveals that it is composed of two, 8 m deep, sub-basins surrounded by an extensive shallow shelf. The drainage network is poorly formed and no distinct inflows exist. Most of the water movement is by groundwater and surface flow especially in 2 or 3 areas of very wet flushes dominated by \textit{Eriophorum vaginatum}.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Lake characteristics</th>
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<tr>
<td>Area</td>
<td>13771 m(^2)</td>
</tr>
<tr>
<td>Volume</td>
<td>37990 m(^3)</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>8.7 m</td>
</tr>
<tr>
<td>Mean depth</td>
<td>2.76 m</td>
</tr>
</tbody>
</table>

2.1.1 Water chemistry

Quarterly records of water chemistry (Table 2) from January 1984 until March 1985 reveal that mean pH has been 4.82 with associated low levels of calcium (Table 2). High aluminium levels of 0.11 mg l\(^{-1}\) were recorded on 23/4/86.

2.1.2 Lake vegetation

Littoral plants in Eiddew Bach were mapped from the shore on the 30th May and seven sublittoral Ekman grab samples were taken on the 21st August 1985 (Fig. 5).

Rushes, \textit{Juncus effusus} in particular, dominate the peaty margins of the western shore. Here the peat is undercut, forming a 0.5m underwater cliff. By contrast the eastern shore comprises large boulders, largely devoid of plantlife. Filamentous algae were abundant during the August visit but apart from extensive stands of \textit{Lobelia dortmanna} on the western side, aquatic macrophytes are scarce (Fig. 5, Table 3). \textit{Sphagnum} moss which is abundant in the surrounding mire systems occasionally encroaches into the water.

*Nomenclature follows Tutin et al. 1964-1980.*
4. Bathymetry and coring locations for Eiddew Bach

Contours in metres
<table>
<thead>
<tr>
<th>Date</th>
<th>pH</th>
<th>Total Oxidised Nitrogen (mg l⁻¹)</th>
<th>Total Alkalinity (mg l⁻¹)</th>
<th>Chloride (mg l⁻¹)</th>
<th>Dissolved Silicate (mg l⁻¹)</th>
<th>Dissolved Sulphate (mg l⁻¹)</th>
<th>Dissolved Sodium (mg l⁻¹)</th>
</tr>
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<tr>
<td>11/06/84</td>
<td>4.3</td>
<td>0.18</td>
<td>1.0</td>
<td>14.0</td>
<td>0.300</td>
<td>6.0</td>
<td>6.3</td>
</tr>
<tr>
<td>11/12/84</td>
<td>5.0</td>
<td>0.20</td>
<td>1.0</td>
<td>9.0</td>
<td>0.428</td>
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</tr>
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<td>2.1</td>
<td>6.4</td>
<td>0.100</td>
<td>4.62</td>
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<td>0.10</td>
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<td>8.6</td>
<td>0.100</td>
<td>4.35</td>
<td>-</td>
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<tr>
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<td>0.30</td>
<td>-</td>
<td>7.0</td>
<td>---</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>23/04/86</td>
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<td>0.12</td>
<td>1.4</td>
<td>8.0</td>
<td>0.230</td>
<td>--</td>
<td>3.9</td>
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<tr>
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<td>0.20</td>
<td>0.6</td>
<td>6.0</td>
<td>0.200</td>
<td>3.55</td>
<td>3.5</td>
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<table>
<thead>
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<th>Date</th>
<th>Dissolved Potassium (mg l⁻¹)</th>
<th>Dissolved Calcium (mg l⁻¹)</th>
<th>Dissolved Magnesium (mg l⁻¹)</th>
<th>Dissolved Zinc (mg l⁻¹)</th>
<th>Dissolved Copper (mg l⁻¹)</th>
<th>Dissolved Lead (mg l⁻¹)</th>
<th>Dissolved Manganese (mg l⁻¹)</th>
<th>Dissolved Iron (mg l⁻¹)</th>
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</thead>
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<tr>
<td>11/06/84</td>
<td>1.0</td>
<td>1.60</td>
<td>0.89</td>
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<td>0.005</td>
<td>0.01</td>
<td>0.14</td>
<td>0.02</td>
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<tr>
<td>11/12/84</td>
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<td>1.04</td>
<td>0.68</td>
<td>0.028</td>
<td>0.005</td>
<td>--</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>06/02/85</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.170</td>
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<td>--</td>
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</tr>
<tr>
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<td>--</td>
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<td>14/03/85</td>
<td>--</td>
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<td>--</td>
<td>---</td>
<td>---</td>
<td>--</td>
<td>---</td>
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<tr>
<td>23/04/86</td>
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<td>0.50</td>
<td>0.64</td>
<td>0.023</td>
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<td>--</td>
<td>0.12</td>
<td>0.04</td>
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<tr>
<td>27/11/86</td>
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<td>0.78</td>
<td>0.57</td>
<td>0.014</td>
<td>---</td>
<td>--</td>
<td>0.11</td>
<td>0.01</td>
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</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Conductivity (μS)</th>
<th>Labile Aluminium (mg l⁻¹)</th>
<th>Dissolved Organic Carbon (mg l⁻¹ C)</th>
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<td>42</td>
<td>0.11</td>
<td>1.2</td>
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<tr>
<td>27/11/86</td>
<td>40</td>
<td>0.09</td>
<td></td>
</tr>
</tbody>
</table>
Table 3: The fringing and aquatic vegetation of Eiddew Bach, August 1985

(Ae abundant; If= locally frequent; r=rare)

i) Marsh fringes (west side)
- Juncus acutifloris (lf); J. articulatus (lf); J. effusus (A);
- Menyanthes trifoliata (r); Sphagnum spp (A).

ii) Littoral zone
- Liverworts including Jungermannia spp (r); filamentous algae (lf);
- Sphagnum (r); Littorella uniflora (r); Lobelia dortmannia (lf);
- Juncus bulbosus var. fluitans (r).

iii) Sublittoral Ekman grab samples (site; depth; substrate; plants)
1. 2.5m; mud; Lobelia (A), Isoetes lacustris (r).
2. 1.5m; rock; ----
3. 2.0m; rock; ----
4. 1.5m; mud; Lobelia (r), Isoetes (A).
5. 2.5m; mud; Isoetes (A).
6. 1.5m; rock; ----
7. 1.0m; rock; ----

2.1.3 Fishing history

Little is known of the contemporary fishery status of Llyn Eiddew Bach (R. Hemsworth pers. comm.). It is small lake and rarely fished.

Cliffe (1860) described the trout in Llyn Eiddew Bach as being much larger (0.5 lbs upwards) than those in the adjacent Llyn Eiddew Mawr. However, owing to its limited extent the lake was not considered much of a fishery.

Ward (1931) reported that the fishing in Llyn Eiddew Bach belonged to Lord Harlech but that it was free. The trout were of 'fine quality'.

2.2 Catchment

Eiddew Bach has a small catchment (123,167 m²) and relatively small catchment:lake ratio (7.9).

Table 4  Catchment characteristics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Total catchment area</td>
<td>123,167 m²</td>
</tr>
<tr>
<td>Area of land in catchment</td>
<td>109,396 m²</td>
</tr>
<tr>
<td>Area of lake</td>
<td>13,771 m²</td>
</tr>
<tr>
<td>Catchment/lake ratio</td>
<td>7.9</td>
</tr>
<tr>
<td>Maximum relief</td>
<td>20 m</td>
</tr>
</tbody>
</table>

2.2.1 Geology

Solid geology dominates the catchment and drift deposits are only found in the northeast of the site. Greywackes of the Rhinog formation of the Harlech grits predominate, while to the southwest fine grained grey siltstones of the Hafotty formation of the Harlech Grits are common. Igneous intrusions also exist and follow easterly running fault lines (Allen & Jackson 1985).
Lobelia dortmanna

2 Ekman grab sample site

5. Lake vegetation for Elddew Bach
2.2.2 Soils

Acid humic rankers belonging to the Revidge association (311a) dominate the catchment soils (Rudeforth et al. 1984).

2.2.4 Present Vegetation

Most of the catchment is characterised by Nardus/Festuca acid grassland with areas of bare rock to the east and Festuca/Nardus to the west. Small amounts of Eriophorum/Sphagnum occur around the incipient drainage channel to the north (Fig. 6).
6. The catchment vegetation of Eiddew Bach
3.0 Methods

3.1.1. Surveying

The lake was surveyed using the techniques described in Stevenson et al. (1987). Shore surveying stations were located on opposite shores at the narrowest section of the lake.

3.1.2. Collection of sediment cores and routine laboratory measurements of sediment characteristics

Cores were taken using a wide diameter piston corer operated from an inflatable boat. Sampling was carried out during August 1985.

Core Eiddew Bach 2, EIB 2, (131 cm) was extruded in the laboratory. The top 20 cm of sediment was sampled at 1/2 cm intervals and the remaining core sampled at 1 cm intervals. Subsamples were then taken for dry weight, loss on ignition (at 550°C) and wet density measurements.

Analyses for dating, magnetics, chemistry, soot, diatoms & pollen were all conducted according to the standard methods set out in Stevenson et al. (1987).
4.0 Results

4.1 Lake history

4.1.1. Sediment Description

Fig. 7 shows the loss on ignition, wet density and dry weight profiles for the EIB 2 core. It can be immediately seen that the core can be divided into two main sections at 21 cm. From 131 cm to 21 cm the core consists of a highly organic (60%) mud with occasional tree bark and leaves (Ld=4, Dg+, Dl+). Throughout this section loss on ignition falls steadily while wet density and dry weight values vary little. Above 21 cm a rapid drop in the loss on ignition values is seen with increases recorded in both wet density and dry weight values. The sediment between 7 and 21 cm consists of a mid-brown organic mud with some coarse and fine detritus and fine sand (Ld=4, Dh+, Dg+, Sa+). Above 7 cm and associated with apparently stabilised low loss on ignition values (20%) the sediment consists of a very dark brown organic mud with occasional herbaceous plant fragments (Ld=4, Dh+, Dg+).

4.1.2. 210Pb dating

Sediments from Eiddew Bach 2 were analysed for 210Pb, 226Ra and 137Cs by gamma spectrometry (Appleby et al. 1986). The 210Pb and 226Ra results are given in Table 5, and shown graphically in Figs. 8 & 9. The 137Cs results are given in Table 6 and Fig. 10. Table 7 gives values of a range of other radioisotopes determined from the gamma spectra. The 210Pb inventory of the core is 1.89 pCi cm⁻², and represents a mean 210Pb flux of 0.06 pCi cm⁻² yr⁻¹. The 210Pb inventories for other nearby lakes indicate that this region may have a low atmospheric 210Pb flux, due possibly to its coastal location. Nonetheless, the value for this core is so low as to cast doubt over the validity of the usual 210Pb dating models. The relatively high 137Cs concentration in the near surface sediments suggests that some post-1950's sediment is present. On the other hand the diatom data indicate a surface sediment hiatus and sediment loss may be the reason for the low inventory. There are no unusual changes in the 226Ra or 40K concentrations (Table 7) which might indicate changes in mineral type. Values of the other radioisotopes in this table are too low to give reliable information.

Fig. 11 shows the 210Pb chronologies for core EIB2 given by the CRS and CIC 210Pb dating models (Appleby and Oldfield 1978). Both models indicate a uniform sediment accumulation rate over the past 30 years of 0.0065 g cm⁻² yr⁻¹. For older sediments the CRS model indicates a significantly reduced accumulation rate whereas the CIC model indicates only a slight reduction. Because of the uncertainties over the 210Pb flux and the difficulty in this case of establishing the precise equilibrium depth it is probably safer to base the chronology on the CIC model although this is also probably in error if recent sediment has been lost. The CRS & CIC model chronologies are given in Table 8 & 9 respectively.

The 137Cs data is of no chronological value for this core. The 137Cs concentrations decline monotonically from a maximum value at the surface, and there are significant concentrations down to 13 cm, well below the 210Pb equilibrium depth.
7. Profiles of variation in dry weight, wet density and loss-on-ignition for the Eiddew Bach 2 core
8. Total $^{210}\text{Pb}$ profile for the Eiddew Bach 2 core

9. Unsupported $^{210}\text{Pb}$ profile for the Eiddew Bach 2 core
Table 5. $^{210}\text{Pb}$ Data for Core Eiddew Bach 2.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Dry Mass</th>
<th>$^{210}\text{Pb}$ Concentration</th>
<th>Standard Errors</th>
<th>$^{226}\text{Ra}$ Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>g cm$^{-2}$</td>
<td>pCi g$^{-1}$</td>
<td>pCi g$^{-1}$</td>
<td>Total Uns. pCi g$^{-1}$ +/-</td>
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<td>0.50</td>
<td>0.0471</td>
<td>7.910</td>
<td>7.249</td>
<td>0.41 0.42</td>
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<tr>
<td>1.75</td>
<td>0.1801</td>
<td>3.900</td>
<td>3.256</td>
<td>0.26 0.27</td>
</tr>
<tr>
<td>2.75</td>
<td>0.2869</td>
<td>3.510</td>
<td>2.581</td>
<td>0.32 0.34</td>
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<tr>
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<td>0.4701</td>
<td>1.580</td>
<td>0.947</td>
<td>0.18 0.19</td>
</tr>
<tr>
<td>5.75</td>
<td>0.6000</td>
<td>0.810</td>
<td>0.198</td>
<td>0.14 0.15</td>
</tr>
<tr>
<td>6.75</td>
<td>0.7046</td>
<td>0.680</td>
<td>-0.117</td>
<td>0.16 0.17</td>
</tr>
<tr>
<td>7.75</td>
<td>0.8116</td>
<td>0.500</td>
<td>-0.184</td>
<td>0.14 0.15</td>
</tr>
<tr>
<td>9.50</td>
<td>1.0251</td>
<td>0.540</td>
<td>-0.176</td>
<td>0.19 0.20</td>
</tr>
<tr>
<td>13.25</td>
<td>1.5002</td>
<td>0.570</td>
<td>-0.128</td>
<td>0.13 0.14</td>
</tr>
</tbody>
</table>

Table 6. $^{137}\text{Cs}$ data for Core Eiddew Bach 2.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Dry Mass</th>
<th>$^{137}\text{Cs}$ Concentration</th>
<th>Cumulative $^{137}\text{Cs}$ Fract</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>g cm$^{-2}$</td>
<td>pCi g$^{-1}$</td>
<td>+/-</td>
</tr>
<tr>
<td>0.50</td>
<td>0.0471</td>
<td>15.98</td>
<td>0.28</td>
</tr>
<tr>
<td>1.75</td>
<td>0.1801</td>
<td>9.31</td>
<td>0.17</td>
</tr>
<tr>
<td>2.75</td>
<td>0.2869</td>
<td>6.41</td>
<td>0.17</td>
</tr>
<tr>
<td>4.50</td>
<td>0.4701</td>
<td>2.45</td>
<td>0.08</td>
</tr>
<tr>
<td>5.75</td>
<td>0.6000</td>
<td>1.32</td>
<td>0.05</td>
</tr>
<tr>
<td>6.75</td>
<td>0.7046</td>
<td>1.03</td>
<td>0.06</td>
</tr>
<tr>
<td>7.75</td>
<td>0.8116</td>
<td>0.66</td>
<td>0.04</td>
</tr>
<tr>
<td>9.50</td>
<td>1.0251</td>
<td>0.60</td>
<td>0.06</td>
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<tr>
<td>13.25</td>
<td>1.5002</td>
<td>0.34</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 7. Other radioisotope data for Core Eiddew Bach 2.

<table>
<thead>
<tr>
<th>Depth</th>
<th>$^{226}\text{Ra}$</th>
<th>$^{228}\text{Th}$</th>
<th>$^{232}\text{U}$</th>
<th>$^{238}\text{Ac}$</th>
<th>$^{40}\text{K}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>pCi g$^{-1}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>0.66</td>
<td>0.27</td>
<td>0.10</td>
<td>0.66</td>
<td>0.27</td>
</tr>
<tr>
<td>1.75</td>
<td>0.64</td>
<td>0.06</td>
<td>0.11</td>
<td>0.74</td>
<td>1.09</td>
</tr>
<tr>
<td>2.75</td>
<td>0.93</td>
<td>0.00</td>
<td>0.17</td>
<td>0.72</td>
<td>0.00</td>
</tr>
<tr>
<td>4.50</td>
<td>0.63</td>
<td>0.50</td>
<td>0.12</td>
<td>0.62</td>
<td>1.10</td>
</tr>
<tr>
<td>5.75</td>
<td>0.61</td>
<td>0.20</td>
<td>0.07</td>
<td>0.45</td>
<td>0.86</td>
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<td>6.75</td>
<td>0.80</td>
<td>0.41</td>
<td>0.07</td>
<td>0.73</td>
<td>1.09</td>
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<tr>
<td>7.75</td>
<td>0.68</td>
<td>0.32</td>
<td>0.06</td>
<td>0.64</td>
<td>1.15</td>
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<tr>
<td>9.50</td>
<td>0.72</td>
<td>0.47</td>
<td>0.14</td>
<td>0.70</td>
<td>0.47</td>
</tr>
<tr>
<td>13.25</td>
<td>0.70</td>
<td>0.58</td>
<td>0.07</td>
<td>0.65</td>
<td>1.29</td>
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</table>
10. $^{137}$Cs profile for the Eiddew Bach 2 core

11. CRS and CIC $^{210}$Pb age/depth chronology for the Eiddew Bach 2 core
Table B. CRS Model $^{210}$Pb chronology

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Dry Mass (g cm$^{-2}$)</th>
<th>Cumul. Unsupp. $^{210}$Pb (pCi cm$^{-2}$)</th>
<th>Chronology</th>
<th>Sedimentation Rate (g cm$^{-2}$ yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AD  Yr Error</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>0.0000</td>
<td>1.89</td>
<td>1965 0</td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>0.0471</td>
<td>1.50</td>
<td>1977 8 2</td>
<td>0.0060 0.058 6.6</td>
</tr>
<tr>
<td>1.00</td>
<td>0.1003</td>
<td>1.15</td>
<td>1969 16 2</td>
<td>0.0063 0.060 8.2</td>
</tr>
<tr>
<td>1.50</td>
<td>0.1535</td>
<td>0.88</td>
<td>1961 24 2</td>
<td>0.0066 0.063 9.7</td>
</tr>
<tr>
<td>2.00</td>
<td>0.2068</td>
<td>0.67</td>
<td>1952 33 3</td>
<td>0.0063 0.059 10.6</td>
</tr>
<tr>
<td>2.50</td>
<td>0.2602</td>
<td>0.50</td>
<td>1942 43 3</td>
<td>0.0052 0.050 10.9</td>
</tr>
<tr>
<td>3.00</td>
<td>0.3131</td>
<td>0.35</td>
<td>1931 54 4</td>
<td>0.0044 0.042 13.3</td>
</tr>
<tr>
<td>3.50</td>
<td>0.3654</td>
<td>0.23</td>
<td>1917 68 6</td>
<td>0.0039 0.037 17.8</td>
</tr>
<tr>
<td>4.00</td>
<td>0.4178</td>
<td>0.15</td>
<td>1903 82 8</td>
<td>0.0033 0.032 22.4</td>
</tr>
<tr>
<td>4.50</td>
<td>0.4701</td>
<td>0.10</td>
<td>1890 95 9</td>
<td>0.0028 0.027 26.9</td>
</tr>
<tr>
<td>5.00</td>
<td>0.5221</td>
<td>0.04</td>
<td>1884 121 11</td>
<td>0.0023 0.022 30.0</td>
</tr>
<tr>
<td>5.50</td>
<td>0.5740</td>
<td>0.02</td>
<td>1839 146 12</td>
<td>0.0018 0.017 33.1</td>
</tr>
</tbody>
</table>

$^{210}$Pb Flux = 0.06 +/- 0.01 pCi cm$^{-2}$
90% Equilibrium Depth = 4.0 cm. or 0.40 g cm$^{-2}$
99% Equilibrium Depth = 5.7 cm. or 0.59 g cm$^{-2}$

Table 9. CIC Model $^{210}$Pb chronology for Core Eiddew Bach 2

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Dry Mass (g cm$^{-2}$)</th>
<th>Chronology</th>
<th>Sedimentation Rate (g cm$^{-2}$ yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AD  Yr Error</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>0.0000</td>
<td>1985 0</td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>0.0471</td>
<td>1978 7 2</td>
<td>0.0069 0.057 9.05</td>
</tr>
<tr>
<td>1.00</td>
<td>0.1003</td>
<td>1970 15 3</td>
<td>0.0069 0.066 9.9</td>
</tr>
<tr>
<td>1.50</td>
<td>0.1535</td>
<td>1963 22 4</td>
<td>0.0069 0.065 9.8</td>
</tr>
<tr>
<td>2.00</td>
<td>0.2068</td>
<td>1955 30 4</td>
<td>0.0066 0.061 9.9</td>
</tr>
<tr>
<td>2.50</td>
<td>0.2602</td>
<td>1946 39 5</td>
<td>0.0059 0.057 9.5</td>
</tr>
<tr>
<td>3.00</td>
<td>0.3131</td>
<td>1937 48 5</td>
<td>0.0055 0.053 9.4</td>
</tr>
<tr>
<td>3.50</td>
<td>0.3654</td>
<td>1927 58 7</td>
<td>0.0055 0.053 9.3</td>
</tr>
<tr>
<td>4.00</td>
<td>0.4178</td>
<td>1918 67 9</td>
<td>0.0055 0.053 9.3</td>
</tr>
<tr>
<td>4.50</td>
<td>0.4701</td>
<td>1908 77 11</td>
<td>0.0055 0.053 9.3</td>
</tr>
<tr>
<td>5.00</td>
<td>0.5221</td>
<td>1899 86 13</td>
<td>0.0055 0.053 9.3</td>
</tr>
<tr>
<td>5.50</td>
<td>0.5740</td>
<td>1870 95 17</td>
<td>0.0055 0.053 9.3</td>
</tr>
</tbody>
</table>

90% Equilibrium Depth = 16.6 cm. or 2.75 g cm$^{-2}$
99% Equilibrium Depth = 31.3 cm. or 6.09 g cm$^{-2}$

* Assumes no loss of surface sediments (see text).
4.1.3. Diatoms and pH reconstruction

Diatoms were analysed from the top 20 cm of the Eiddew Bach 2 core. The uppermost 6 cm encompasses the $^{210}$Pb dated portion of the core. Fig. 12 shows the dominant diatom taxa in the core. Diagrams showing the stratigraphy of all taxa are included in Appendix A.

Only a small number of taxa are common (＞2%) in the analysed sediments from Eiddew Bach. Except in the uppermost samples the flora is dominated by the planktonic Cyclotella kutzingiana (circumneutral) and the periphytic Fragilaria construens var. venter (alkaliphilous) and Achnanthes minutissima (circumneutral), with shifting proportions of Cyclotella kutzingiana and Achnanthes minutissima relative to Fragilaria construens var. venter. This flora is typical of oligotrophic clearwater lakes and is similar to the pre-acidification flora of Llyn Hir (Fritz et al. 1986), although percentages of Anomoeoneis vitrea, Fragilaria virescens and Melosira perglabra var. florineae are higher in the Llyn Hir sediments.

Above 8 cm a number of acidophilous and undesignated Navicula species appear and increase in abundance, including Navicula mediocris, N. madumensis, N. indifferentis, N. heimansii and N. tenuicephala. The most marked changes occur in the uppermost 2 cm where Cyclotella kutzingiana and Fragilaria construens var. venter decline in relative abundance and Fragilaria virescens, Navicula sp. 1, Navicula seminula, Navicula hassisana and Anomoeoneis vitrea increase. The decline of the planktonic Cyclotella kutzingiana and the alkaliphilous Fragilaria construens var. venter suggests the incipient stages of acidification of Eiddew Bach (see Flower et al. 1985). This post-1950 onset of acidification at Eiddew Bach is considerably later than the correlative changes at Llyn Hir (Fritz et al. 1986), where the Cyclotella decline dates from the early 19th century.

pH reconstructions using index B-Scandinavia and index B-Galloway (Flower 1986) suggest a lakewater pH of 6.7 - 6.9 during the deposition of the basal 10 cm of analysed sediments. Between 10.0 and 2.5 cm pH values increase 0.3 units and subsequently fall, paralleling changes in the relative abundance of the alkaliphilous dominant Fragilaria construens var. venter. In the uppermost 2.5 cm pH values continue to decline 0.4 units below the pH of the basal sediments, paralleling the decline of Cyclotella kutzingiana and Fragilaria construens var. venter and the increase of several acidophilous Navicula spp. pH reconstructions using multiple regression of pH groups (Flower 1986) suggest fluctuating pH between 6.5 and 6.7, with no net change over the 20 cm sedimentary sequence.

All three pH reconstruction equations suggest a mean lakewater pH of 6.3 - 6.7 during deposition of the 0 - 0.5 cm sediment, whereas the present lake pH (Table 2) ranges from 4.3 - 5.4.

The diatom assemblage in the uppermost core sample is clearly atypical among pH 4.8 lakes, as indicated by the discrepancy between the reconstructed pH of that sample and present lakewater pH. The probable explanation for the poor fit of the pH reconstruction is that the core site is not presently accumulating sediment. This implies that the diatom assemblage at the top of the core is not a contemporary flora and hence should not reflect the current lakewater chemistry. Depositional hiatuses are clearly quite common.
12. Diatom summary diagram for the Eiddew Bach 2 core
in the highland lakes of Wales (Stevenson et al. 1987ab, Kreiser et al. 1986, Patrick & Stevenson 1987), including an earlier hiatus for Eiddew Bach at 20 cm (see section 4.1.7). Further evidence suggesting that the topmost sediments are absent from the core comes from evidence of a Kajak core top which has a far more acid tolerant flora present.

The low 210Pb inventory of Eiddew Bach is consistent with a contemporary hiatus in deposition, although the presence of 137Cs suggests that occurs after 1954 (see section 4.1.2). And that the major period of lake acidification also occurred after this date. Data from both Llyn Gwyn (Stevenson et al. 1987) and Llyn Llagi (Patrick et al. 1987) suggest that at these sites major acidification occurred quite late (post-1950).

Although we are presently unable to generate pH reconstructions for Eiddew Bach, we are still able to draw qualitative conclusions from the diatom data. The decline of Cyclotella kutsingiana, a common feature in many of the Scottish and Welsh lake stratigraphies, and the increased abundance of several acidophilous Navicula species are clearly indicative of incipient stages of lake acidification. The surface sample from a Kajak core obtained earlier in 1985 contained very low percentages of Achnanthes minutissima and the presence of the acidobiontic species Tabellaria quadrisetata.

4.1.4 Sediment chemistry

Major ions

There are some major changes in the constitution of the Eiddew Bach core (Fig. 7). Above 20 cm the organic content falls from very high values around 70% to lower values around 25%. This change is accompanied by an increase in dry weight. Above 20 cm then coarser sediment with a much lower organic content was deposited. This 20 cm level when there was a change in the erosion regime from the catchment is before the dated part of the core (Table 9).

This change has a major effect on the major cation composition of the sediment (Fig. 13). The concentrations of sodium, potassium and magnesium all increase in the upper 20 cm of the sediment. A rise in concentrations would be expected because of the large decrease in organic content but the concentrations of these cations in the mineral component of the sediment also increase (Fig. 14). These changes in cation concentration in the upper 20 cm imply a change to higher erosion rates in the catchment (Engstrom & Wright 1984, Harkereth 1986).

While the behaviour of sodium, potassium and magnesium is similar that of calcium is different. Its profile is similar to that of loss on ignition. This was also found in the other Welsh lakes in the study (Fritz et al. 1986, Kreiser et al. 1986, Stevenson et al. 1987b, Fritz et al. 1987).

Trace metals

The change in sediment constitution above 20 cm which produces the rise in major cation concentration can be expected to produce an increase in trace metal concentrations. This must be taken into account in order to reveal contamination of the sediments by trace metals.
13. Variations in Na, K, Mg & Ca gdw⁻¹ for the Eiddew Bach 2 core
15. Variations in Pb & Zn g dw⁻¹ for the Eiddew Bach 2 core
16. Variations in Ni & Cu g dw^{-1} for the Eiddew Bach 2 core
17. Variation of trace metal concentrations with depth for Eiddew Bach expressed as per gram minerals
18. Variations in Zn/Mg & Pb/K concentrations for the Eiddew Bach 2 core
Two points indicate that there is zinc and lead contamination in the upper 7.5 cm of sediment (Figs. 15 - 17). Comparing the zinc and lead profiles with magnesium for example shows that the zinc and lead concentrations increase above 20 cm like magnesium but that above 7.5 cm they increase greatly while the magnesium concentration remains roughly constant. There is an additional source of these trace metals which causes the concentrations to rise further.

Secondly, when the zinc and lead concentrations are plotted against either sodium, potassium or magnesium there is a good linear relationship below 7.5 cm but above this the trace metal concentrations are higher than expected on the basis of the cation concentrations. This is illustrated by two such plots (Fig. 18). The natural linear relationship is established before contamination starts and this is destroyed when there is an additional source of the trace metals.

There is contamination of the upper 7.5 cm of the sediment by zinc and lead while there is little if any contamination by copper and nickel. This depth is outside the dated part of the core but a rough date by extrapolation is 1850 A.D. (using 0.053 cm yr⁻¹, Table 9). This contamination as in the other Welsh lakes studied is from the atmosphere. Trace metal containing wastewaters in this remote lake is very unlikely.

The sedimentary fluxes of the trace metals are low. This has been found in all but one of the lakes in north-west Wales (Stevenson et al. 1987). The most likely reason for this is that the low dry mass accumulation rates mean that the trace metal sedimentation efficiency is low.

**Sulphur**

The sulphur profile is similar to that of the loss on ignition, especially above 100 cm (Fig. 19). There is no strong evidence that the sediments record an increase in the deposition rate of sulphur from the atmosphere. Above 7.5 cm where zinc and lead provide evidence for contamination from the atmosphere the sulphur concentration drops. A relationship between the sulphur and loss on ignition profiles was found in Llyn y Bi (Fritz et al. 1987) and so in certain circumstances the size of the natural inputs of sulphur to the sediment and microbiological cycling within the lake can obscure any record of increased atmospheric loadings.

4.1.5. **Carbonaceous particle**

The carbonaceous particle pattern for Eiddew Bach, illustrating the number of particles per gram dry sediment is given in Fig. 20 & Table 10. It shows the presence of soot in small numbers at a depth of 22 cm onwards. Two small peaks in concentration are seen at 9 cm and 5 cm. The onset of a rapid rise in concentration occurs from 3 cm.

The pattern for the soot count in terms of the organic content of dry sediment is given in Fig. 21. Soot patterns in terms of the organic fraction of sediment (using LOI) may be considered to be more precise as the supply of organic material to the sediment tends to be more uniform over time than the input of mineral matter which can vary widely. Using LOI as a base has the effect of 'smoothing' the soot pattern, and this can be observed for Eiddew Bach. Otherwise, the pattern is very similar to that in...
19. Variations in S for the Eiddew Bach 2 core
20. Carbonaceous particle record gdw\(^{-1}\) for the Eiddew Bach 2 core

21. Carbonaceous particle record per gram mineral dry weight for the Eiddew Bach 2 core
Table 10: Carbonaceous particle analysis for Eiddew Bach 2

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>per g dry sed x 10^3</th>
<th>per g organic content x 10^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 - 0.5</td>
<td>7.04</td>
<td>23.1</td>
</tr>
<tr>
<td>1.0 - 1.5</td>
<td>4.59</td>
<td>18.2</td>
</tr>
<tr>
<td>2.0 - 2.5</td>
<td>1.61</td>
<td>6.1</td>
</tr>
<tr>
<td>2.5 - 3.0</td>
<td>0.60</td>
<td>2.1</td>
</tr>
<tr>
<td>4.0 - 4.5</td>
<td>0.17</td>
<td>0.5</td>
</tr>
<tr>
<td>5.0 - 5.5</td>
<td>1.04</td>
<td>3.4</td>
</tr>
<tr>
<td>6.0 - 6.5</td>
<td>0.22</td>
<td>0.7</td>
</tr>
<tr>
<td>7.0 - 7.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8.0 - 8.5</td>
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<td>0.4</td>
</tr>
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</tr>
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<td>0</td>
</tr>
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<td>11.0 - 11.5</td>
<td>0.08</td>
<td>0.3</td>
</tr>
<tr>
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<td>0.07</td>
<td>0.2</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>14.0 - 14.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0.2</td>
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<td>0</td>
</tr>
<tr>
<td>17.0 - 17.5</td>
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<td>0.3</td>
</tr>
<tr>
<td>18.0 - 18.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19.0 - 19.5</td>
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<td>0</td>
</tr>
<tr>
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</tr>
<tr>
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<td>0.1</td>
</tr>
<tr>
<td>24.0 - 25.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26.0 - 27.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>28.0 - 29.0</td>
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<td>0</td>
</tr>
<tr>
<td>30.0 - 31.0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Fig. 20.

4.1.6. Magnetic Measurements

Sediments from Eiddew Bach core 2 were packed into previously screened styrene pots and subjected to the following sequence of magnetic measurements:

1. Anhysteritic Remanent Magnetization (ARM) using a Molspin AF Demagnetizer set with a peak AF field of 100mT and a DC bias of 0.04mT.

2. ‘Saturation’ Isothermal Remanent Magnetization (SIRM) using a Molspin Pulse Magnetizer with a maximum DC field of 850mT.

3. Isothermal Remanence (IRM) measured at each step in a sequence of reverse field DC demagnetization at -20mT, -40mT, -100mT and -300mT for samples from 0 – 30 cm.

All remanences were measured on a Minispin Slow-speed spinner Fluxgate Magnetometer. Susceptibilities were not measured as the combination of small sample size and relatively weak magnetization made the samples unsuitable.

Fig. 22 plots the magnetic measurements for this core. The right hand graph shows reverse field ratios (IRM/ARM) plotted against a horizontal scale of percentage reverse-saturation. Thus 50 represents the point during DC demagnetization at which IRM is zero and 100 represents the point at which IRM/SIRM is -1.

The noisy SIRM/ARM quotient, especially below 20 cm, reflects ARM measurements close to the instrumental noise limit. SIRM values are also very low below this depth and reverse field ratio measurements were discontinued below 30 cm. The increase in ARM and SIRM around 20 cm dates from several centuries before present and would appear to reflect a change in sediment regime maintained from that time onwards but unrelated to atmospheric deposition or industrial processes. The increases in SIRM, ARM and SIRM/ARM above 3.5 cm parallel those found in late 19th and 20th century peats.

4.1.7. Pollen

Figs. 23 & 24 present summary pollen diagrams of the Eiddew Bach core. Appendix B contains the full pollen diagram.

The diagrams have been zoned according to the zonation program of Birks & Gordon (1985).

EID-1. Pinus / Ulmus / Quercus PAZ (131 - 98 cm)

The high but declining values of Betula and high values of Quercus, Ulmus and Pinus clearly indicate that the zone represents an early postglacial wooded landscape around Eiddew Bach. Since values of Alnus are low the suggested timespan is between 8500 and 7500 B.P. The end of the zone probably dates to ca. 7500 B.P. as suggested by the increase in Alnus values marking the beginning of a pronounced alder rise (Smith 1984).
22. ARM, SIRM and SIRM/ARM versus depth, 0-130 cm. Reverse field ratios (see text) are plotted for the top 30 cm only.
Eiddeu Bach

23. Summary pollen diagram for the Eiddeu Bach 2 core. Trees expressed as a percentage of the arboreal pollen. All other groupings as a percentage of the arboreal pollen + the respective grouping.
Eiddew Bach

24. Summary pollen diagram for the Eiddew Bach 2 core. All taxa expressed as a percentage of the arboreal pollen + peatland indicators sum
The high values of Quercus and Alnus pollen throughout this zone clearly indicate the establishment of an extensive oak and alder forest within the catchment. Small open patches in the generally acid soils are dominated by Calluna and Gramineae. The zone covers a period from approximately the time of the alder rise (7500 B.P.) to the elm decline (5500 B.P.). The end of the zone is clearly marked by a 5000 - 5200 year long hiatus before sedimentation recommences in the early 1800's.

Throughout the zone a progressive but small increase in the amount of open acid moorland habitat within the oak and alder forest is indicated as values of Calluna, Gramineae and Sphagnum all rise mid-way through the zone. At the same time indicators of general regional forest disturbance such as Fraxinus and Plantago also increase.

A marked erosion phase is also associated with this disturbance phase and is marked by a collapse in the pollen values of Isoetes (cf Fritz et al 1987, Stevenson et al. 1987) and peaks in the loss on ignition curve.

The recommencement of sedimentation within the core appears to have occurred in the early eighteenth century. The catchment is now dominated by pollen indicators of open moorland (Calluna and Gramineae). Agricultural indicators suggest intensive agricultural activity with the extremely high values of Plantago and Rumex.

4.2 Land use and Management (1)

4.2.1 Land use

At over 350 m on acidic soils the Llyn Eiddew Bach catchment consists of unimproved moorland utilised for rough grazing. In terms of its vegetational composition (see Section 2.1.3) it contains species representative of 'grassy heath' (eg. King 1977, Ball et al. 1982).

In terms of the ADAS (2) land capability classification the catchment comprises land of categories H3 - 'improvements generally severely limited but of moderate or high grazing value' and H4 - 'generally not improvable and of low grazing value' (MAFF 1980).

The altitude, soil acidity, wetness of the land immediately to the north of the lake and the rocky terrain to the east (the greater proportion of the catchment - Fig. 6) determine that the catchment is inherently unimprovable. There is no evidence from documentary sources (see below), from air photographs, or on the ground to suggest that the catchment has ever supported a land use other than rough moorland grazing.

It is unreasonable to expect any attempt to have been made towards improving the acid moorland with lime. Merioneth is almost entirely devoid of limestone deposits and in the 19th century the high price of imported lime together with the cost of carriage over poor roads, ensured that it was
rarely used in remoter areas (Davies 1813). Contemporary farmers (A. Griffiths, G. Lloyd pers. comms.) and authorities (D. Jarrett pers. comms.) confirm that agricultural lime has not been applied to the catchment in living memory.

**Documentary evidence (3)**

The tithe map and schedule of Llanddecwyn (4) describe the catchment as 'mountain land' but the state of cultivation as 'pasture'. The notation 'pasture' does not necessarily indicate improved grazing land (cf. Morgan 1959, Kain and Prince 1985).

The unimproved nature of the catchment was suggested by Murray (1885) who described the 'wild scenery' around the Eiddew lakes.

The first and subsequent editions of the six inch ordnance survey map of the area (5) show the catchment to consist of 'rough or heathy pasture', with the wet area at the north of the lake described as 'marsh'.

The First Land Utilisation Survey six inch manuscript map of 1937 (6) classifies the lake catchment in the 'moorland/rough grazing' category. The Second Land Utilisation Survey six inch manuscript map of 1970 (7) indicates a vegetation cover and distribution very similar to the present situation.

The Crown common on which the catchment lies was grazed primarily by the Haesneuadd Estate until ca. 1950. However, papers in the Haesneuadd collection at UCNW Bangor provide no historical information on the land use or management of the Llyn Eiddew Bach area.

**Non agricultural land use**

Tracks to the south and west of the lake (8) provided access to mineral workings (primarily manganese mines) outside of the catchment to the east. However, there is no evidence from documentary sources or on the ground to suggest that any mineral was ever exploited or prospected for within the lake catchment.

4.2.2 Land management

**Pastoralism**

Until the mid-19th century black cattle were an important component of the pastoral economy of north Wales (Roberts 1959, Emery 1965, Hughes et al. 1973). Goats also ranged the hills in significant numbers (Evans 1812, Roberts 1959, Emery 1965, Hughes et al. 1973), as did young ponies which stayed on the hills year round (Davies 1813). However, the central issues of pastoral management in the catchment concern its utilisation for sheep grazing.

The only quantitative data relating to sheep numbers in the vicinity of Llyn Eiddew Bach are those of the annual parish agricultural returns of Llanddecwyn (9). These were analysed at quinquennial intervals and are presented in Fig. 25.

Although they represent the source of information most applicable to the Llyn Eiddew Bach catchment, the spatial resolution of these data do not
25. Sheep numbers in Llanddedywn parish 1867-1983
permit catchment-specific assertions to be drawn and their interpretation is hindered by several other constraints. In particular they take only a limited account of changes in sheep type and no account of changes in grazing regime (Patrick 1987).

Sheep numbers have increased in the period 1867-1983. (Fig. 25). The increasing significance of ewes and lambs at the expense of wether sheep over the last century, is also suggested from Fig. 25.

However, within the Llyn Eiddew Bach catchment a broad decrease in sheep numbers has been recognised since ca. 1950 (A. Griffiths, D. Lloyd pers. comms.). An example is thus apparent whereby parish data prove misleading in the context of a small catchment such as Eiddew Bach (cf. Patrick 1987).

A change in grazing regime has been apparent through the late 19th and 20th centuries. The transition from hardy wethers to ewes and lambs, the declining viability and eventual abandonment of the higher farms and the greater availability of winter grazing on lower land, has resulted in fewer sheep over-wintering on the high hills and a shortening of the grazing season at these altitudes (Patrick 1987).

Until the 1970’s sheep were washed in the lake prior to shearing (A. Griffiths, D. Lloyd pers. comms.). A now derelict sheep pen on the southern shore of the lake was the focus of that activity. Another derelict sheep pen at the western edge of the catchment provides further evidence of a higher intensity of sheep grazing in the past (10).

Contemporary farmers (A. Griffiths, D. Lloyd pers. comm.) can recall no burning in the catchment since the 1950’s, although the adjacent catchment of Llyn Eiddew Mawr is periodically burnt. Aerial photographs taken in 1946 (11) indicate strips and patches of burnt land surrounding, but not in the catchment of Llyn Eiddew Bach.

The catchment lies in the Snowdonia National Park but the Park Authority exert no direct control over contemporary management practices.

Subsidiary management practices

There is no evidence that this area was ever managed for game nor that game was actively pursued in the locality of the catchment.
5.0 Conclusions

i) Sediment accumulation rates over the last 100 years at the core site were low, the $^{210}$Pb inventory is very low, and there is evidence that sediment from the last two decades or so is missing from the top of the core. This is indicated by the presence of a carbonaceous particle increase at about 2 cm, usually dated to 1930-1940 at other sites and high values of $^{137}$Cs in the surface sediments. The top 2-3 cm therefore represent sediment accumulated between the 1930's and 1960's.

ii) The diatom based pH reconstructions suggest that the pH of Eiddew Bach was 6.7 - 6.9 throughout the basal 10 cm of analysed sediment. From 8 cm a number of acidophilous taxa and undesignated Navicula species appear and increase in abundance, including Navicula heimansii, N. meidocris, N. indifferens, N. tenuicephala and Navicula madumensis. From 2 cm the most marked change occurs indicating incipient acidification as the planktonic Cyclotella kutsinghiana and the alkaliphilous Fragilaria construens var venter decline and acidophilous taxa like Navicula hassica increase.

iii) The core chemistry record demonstrates that trace metal contamination by lead and zinc of the lake sediments began at 7.5 cm. There appears to be no contamination of the sediments by copper and nickel. The cation chemistry record identifies a major change in erosion rates from the catchment at 20 cm and correlates with the major changes in the pollen record.

iv) The contamination of the sediments by carbonaceous particles commences at 9 cm, earlier than the beginnings of lake acidification. The concentration of these particles increase rapidly from 3 cm and parallel the incipient acidification of the lakewater as suggested by diatom analysis. A similar trend is shown by the magnetic data.

v) The recent portion of the pollen diagram indicates that little change has occurred in the catchment vegetation over the last 150 years. The pollen diagram also reveals a major hiatus in the core at 21 cm below which sediments dating to approximately the elm decline ‘ca. 5000 B.P.’ occur. A period of catchment erosion is identified by an Isoetes decline from 50 cm to 20 cm and matches a period of increased cation concentrations in the lake sediments.

vi) No appreciable land use change has occurred within the catchment. While sheep numbers have increased in the area in recent years the documentary evidence is not precise enough to assess whether the catchment has experienced a significant increase in grazing pressure. No liming has taken place within the catchment and burning has not been a significant management practice.

vii) Since it appears that recent sediment is missing from the top of the core it is not possible to present a complete picture of changing pH through time. However, it is possible to demonstrate that a substantial acidification of the lake has occurred over the last 50 years or so. High concentrations of carbonaceous particles in lakes have only occurred since the 1930's. On this basis the uppermost 2 cm of the core clearly postdates 1930 and contains a diatom assemblage indicative of pH values $> 6.0$. Since the present pH is about 4.5 a pH decline of approximately 1.5 units must have occurred over the last few decades. Since no significant catchment changes have taken place during this period we must conclude as for other
sites in the areas, that the acidification has been caused by acid deposition.


Emery, B.V. (1965) 'A note on the sheep - cattle ratio in Snowdonia, 1570', University College of Wales, Aberystwyth, Symposia in Agricultural Meteorology, Memorandum. 8: 54-55


7.0 Acknowledgments

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8.0 Notes

1. See Patrick (1987) for definitions of 'land use' and 'land management'.

2. ADAS - Agricultural Development Advisory Service (MAFF). Manuscript 1:25,000 maps accessed at ADAS Aberystwyth.

3. See Patrick (1987) with regards to sources (and their interpretation) used in documenting land use and land management change.

4. Tithe map and schedule for the parish of Llanddecwyn, 1841. PRO (Kew) IR30 52/16.


6. Held at the London School of Economics archive.

7. Held at King's College London Geography Department. Sheet no. 532.

8. The first cartographic record of these tracks is from the Ordnance Survey Surveyor's Drawings (British Map Library sheet no. 302, drawn 1819, published 1837-1840, 2 inches/1 mile).

9. PRO (Kew) Class MAF 68.

10. The first cartographic record of this structure is from the first edition Ordnance Survey 6 inch map (see note 5).

| AC120A | ACHNINES LINEARIS | GRUN. |
| AC120C | ACHNINES LINEARIS V FUSILLA | GRUN. |
| AC123A | ACHNINES MICROCEPHALA | GRUN. |
| AC202A | ACHNINES CLUVIA V PEROSTRA | GRUN. |
| AC121A | ACHNINES MINUTISSIMA | GRUN. |
| AC121C | ACHNINES AUSTRIACA | GRUN. |
| AC122A | ACHNINES RUFIFILA | GRUN. |
| AC122C | ACHNINES MARGINALATA | GRUN. |
| AC123A | ACHNINES URAMA | GRUN. |
| AC202A | ACHNINES ALYNA | GRUN. |
| AC202C | ACHNINES URAMA | GRUN. |
| AC203A | ACHNINES ENVIS | GRUN. |
| AC203C | ACHNINES ENVIS | GRUN. |
| AC204A | ACHNINES OPHIO | GRUN. |
| AC204C | ACHNINES OPHIO | GRUN. |
| AC205A | ACHNINES SP | GRUN. |
| AC205C | ACHNINES SP | GRUN. |

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