*LOWESWATER CARE PROJECT: SHORT PROJECT REPORT*

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Linking Historical Land-Use Change with Palaeolimnological Records of Nutrient Change in Loweswater, Cumbria.

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This report details the findings of a short research project commissioned as part of the Loweswater Care Project (http://www.lancs.ac.uk/fass/projects/loweswater/) in 2009. The research presented here sought to discover whether any relationship could be established between the chronology of nutrient enrichment in Loweswater recorded in environmental evidence and changing patterns of land use recorded in historical sources. In so doing it aimed to contribute to an answer to the question: have changes in farming in the Loweswater catchment since *c.* 1800 contributed to the nutrient enrichment of the lake?

**1. Methodology**

The core objective of the project was to relate the findings of the palaeolimnological study of Loweswater using a sediment core collected in 1999 (Bennion *et al*., 2000a) to historic data on land use and changing patterns of farming. The palaeolimnological study (reported in section 3, below), which involved analysis of the remainsof diatoms (single celled, siliceous algae) from the core, identified two periods of nutrient enrichment in the lake, one in the mid-nineteenth century, the second *c*. 1950. The historical research undertaken in 2009-10 (presented in section 2, below) sought to establish the trajectories and chronology of land use change since *c.* 1800. The annual Agricultural Returns (in The National Archives, MAF 68) provide statistics at parish level from 1866 to 1988, enabling land use change from the mid-nineteenth to the late twentieth century to be reconstructed in some detail. Such detailed evidence is lacking before 1866; almost the only snapshot of farming in the parish as a whole is a list of estimated sheep flock sizes gathered as part of the tithe commutation process in 1839 (in The National Archives, IR 18/694). A subsidiary aim of the historical research was to attempt to reconstruct long-term patterns of land use change since the sixteenth century, using data on livestock numbers. To that end, probate inventories of male testators in Loweswater in the period 1580-1650 (in Lancashire Record Office, WRW (C)) were examined. These record the possessions of the deceased, including the value and (at this early date) often the number of livestock they had. Other contextual evidence for the history of farming in this part of Cumbria was also used to flesh out the statistics gathered from these sources.

**2. Land-Use in the Loweswater catchment, c. 1600 to 1988**[[1]](#footnote-1)

***2.1 Land-Use Change 1866-1988***

The parish summaries of the annual Agricultural Returns from 1866 to 1988 have been used to reconstruct land use change from the mid-nineteenth to the late twentieth century in some detail. The key data on crop acreages and livestock numbers are given in Appendix I and Appendix II, which present the arithmetical means for each quinquennium, rather than the actual annual figures, in order to highlight the main features of chronological change. In summary, the major trends are as follows:

*Crops (see Appendix I)*

The broad trend was one of declining acreages under tillage, with short-lived reversals during the ploughing-up campaigns of the First and Second World Wars (Figure I).

**Figure I**

Oats was the main crop, far outstripping the acreages under roots and other cereals. In the later nineteenth century the acreage under each crop in the parish were typically in the order of:

* Oats: 175 acres
* Barley and Wheat: under 10 acres each and declining rapidly
* Potatoes: 30 to 40 acres
* Turnips (including swedes and mangolds): around 60 acres.

All tillage had declined by the inter-war years, wheat and barley almost to extinction; oats to around 130 acres; potatoes to around 20 acres; turnips to around 45 acres. A major change took place from 1955. The acreage under oats fell rapidly, from around 100 acres in the later 1950s to 25 acres in 1965, after which the crop more or less ceased to be grown. Barley cultivation, which had almost ceased by 1900, saw a revival after 1960, accounting for over 20 acres for most of the 1970s. The acreage under root crops also underwent significant change in the mid 1950s, potatoes dropping suddenly to under 10 acres from 1954 and turnips showing a similar decline (from over 50 acres in the early 1950s to around 20 acres by 1970).

*Livestock (see Appendix II)*

The statistics show an intensification of livestock husbandry, with a period of significant change again being visible in the mid-twentieth century (Figure II).

**Figure II**

After rising across the later nineteenth century, the number of cattle remained comparatively stable at around 600-700 until after the Second World War. Numbers averaged around 800 between 1945 and 1955 but then almost doubled to over 1500 by the 1970s. The structure of the cattle herds also changed at this time: cows and heifers, which had accounted for around one-third of the total from 1866 to the 1930s, increased as a proportion of the total numbers to stand at around 50% by 1950.

Sheep numbers fluctuated quite widely from year to year, but totalled in the range 6,500 to 7,500 most years from the 1870s to the 1940s. They showed a modest upward trend between 1950 and 1980 but then increased substantially during the 1980s, standing at over 13,000 by 1988.

In summary, leaving to one side the rapid increase in sheep numbers during the 1980s, it is possible to identify the two decades between 1945 and 1965 as a period of marked land use change in Loweswater. Between those dates cultivation declined significantly: the acreage under oats dropped from around 180 acres to under 25; potatoes from around 40 acres to 5; and turnips from around 55 acres to under 25. Concurrently, there was a marked increase in the numbers of cattle in the parish, from around 800 in the late 1940s to over 1,000 by 1965. The proportion of cows and heifers in the herds, which had begun to increase in the 1930s settled at around 50% of the total number of cattle.

## Mid-twentieth Century Changes: a closer analysis

A closer analysis of the returns for the twenty-one years from 1945 to 1965 inclusive reveals more details of the transition in farming in Loweswater across those two decades. The key elements centre on developments in grassland management. The decline in arable cultivation paralleled the replacement of working horses by tractors (see Table 1, below). The number of working horses, which had stood at between 50 and 60 for most of the first half of the twentieth century, halved between 1950 and 1953 and continued to fall until 1958 (the last year for which statistics on working horses were collected). Although the acreage under oats did not decline as rapidly as the number of working horses, it seems likely that much of the oats, which formed the bulk of the acreage under cultivation, was consumed by horses on the farm.

### Table 1: Working Horses and Acreage under Oats, 1945-1958

*Year Horses Index Oats (acres) Index*

*(1945 = 100) (1945 = 100)*

1945 57 100 174 100

1948 57 100 182.25 105

1949 51 89 174.25 100

1950 50 88 183 105

1951 41 72 163.25 94

1952 30 53 154.5 89

1953 26 46 127 73

1954 23 40 119.25 69

1955 22 39 92 53

1956 18 32 104 60

1927 16 28 97.75 56

1958 13 23 90.25 52

The acreage freed up by the decline in cultivation totalled approximately 200 acres between 1945 and 1965 (total crop acreage in 1945 was 271 acres; in 1965 it was 73 acres, a difference of 198 acres). Across the same period, the acreage of improved grassland (i.e. excluding rough grazing) increased by approximately 600 acres from 1,598 acres in 1945 to 2,197 acres in 1965. The difference was presumably accounted for by improvement of rough grazing.[[2]](#footnote-2) The statistics show that the bulk of the increase in grassland was for pasture: the combined acreage of rotational and permanent grass for mowing rose by 10% between 1945-9 and 1960-4, while the acreage of grass for grazing rose by 26% over the same period.

The overall shift, therefore, was away from cultivation and towards more intensive use of grassland, allowing both cattle and sheep numbers to rise: Loweswater was supporting over 100 more cattle in the mid 1960s than it had in the late 1940s, and almost 2,000 more sheep (see Appendix II). The cattle herds were also changing in structure and character. As noted above, from the 1930s cows and heifers came to form an increasing proportion of the total herd. This appears to be an indication of a trend from small-scale dairying towards suckler herds, the increasing proportion of cows and heifers resulting from the sale of followers at a younger age. In the dairying system young females were brought into the milking herd when three years old; by the 1960s, most young were sold at 12-14 months.[[3]](#footnote-3) That trend was accompanied by a shift towards beef cattle across the 1950s and early 1960s. From 1960 the proportion of beef cattle among the cows in milk increased from the level of around 15% it had been in the 1950s to 27% in the period 1961-5.

These changes were almost certainly accompanied by an increase in the use of artificial fertilizers, though local data on fertilizer use are very limited indeed. The traditional fertilizer applied to grass in northern and western England in the earlier twentieth century was basic slag (Whetham, 1978, p. 4). Almost the only local data specific to Loweswater come from the National Farm Survey in 1941, which recorded fertilizer use in the baldest of terms (‘adequate’; ‘to some extent’ or ‘not at all’). Most farms in Loweswater were recorded as using some fertilizer on grass land but only on four of the larger farms (High Nook, Kirkgate, Oakbank and Waterend) were amounts thought to be ‘adequate’. At Watergate and at Park no fertilizers were used on grass.[[4]](#footnote-4)

Nationally, expenditure on fertilizers and lime surged between the mid-1940s and the mid- 1960s, the increases taking place in two distinct phases. From a plateau of £27 million in the years 1943-6, it rose to £66 million in 1952, levelling off again until 1955, when expenditure again took off, almost doubling to reach a plateau of around £120 million in the mid-1960s. As the price of fertilizers fell during the second phase, the increased expenditure between 1955 and 1962 represented a revolution in fertilizer application (Marks and Britton, 1989, pp. 254-5). In a Cumbrian context, the local farmers’ cooperative, West Cumberland Farmers, noted an increase in sales of fertilizers in their annual report for 1954 and higher applications of fertilizers on grass in their 1957 report.[[5]](#footnote-5) The close correlation between this evidence for a surge in fertilizer use in the 1950s and the switch from horse to tractor power is unlikely to be coincidental: the ‘spinner’ run from a Ferguson tractor’s power take-off revolutionised fertilizer application. Local information suggests that the compound fertilizer in widespread use in the later 1950s and 1960s was a 12:12:18 NPK compound but that this was replaced by a more nitrogen-rich compound (such as 12:5:5) as the high potash content of the 12:12:18 mixture increased the incidence of ‘staggers’ in cattle.[[6]](#footnote-6)

***2.2 Assessing trends in livestock numbers from c. 1600 to the mid-19th century.***

Establishing long-term trends in land use and livestock numbers in Loweswater since the sixteenth century is challenging due to the paucity of evidence. Snatches of local evidence and the conclusions drawn from studies of areas nearby strongly suggest that sheep farming predominated and that the farming system recorded in the later nineteenth-century Agricultural Returns, discussed above, was comparable in broad outline to that obtaining *c*.1600. The numbers of sheep and the size of sheep flocks excited comment in the later seventeenth century: Thomas Denton, surveying Cumberland in 1687-8, commented on the importance of sheep in several Lake District parishes, including Lorton, where he noted the ‘vast stocks of sheep’ on the fells (Winchester and Wane, 2003, p. 120). A similar picture of Loweswater itself was painted by the lord of the manor, Sir Wilfrid Lawson, in the 1690s, when he commented on the ‘Great Stockes of sheape’ there, noting that some tenants had flocks of 500.[[7]](#footnote-7)

How these late seventeenth-century stocking levels compared with stock numbers recorded in the nineteenth century is unclear. An estimate of sheep numbers in 1839 provides a figure of 6,144,[[8]](#footnote-8) not dissimilar from the total figures recorded in the Agricultural Returns before the 1890s (see Appendix II). Elsewhere in the Lake District, sheep numbers appear to have risen across the eighteenth century, giving rise to concerns about overgrazing of the fells by *c*. 1800 and being one of the main drivers of enclosure of common land in Cumbria (Searle, 1993; Rodgers *et al.*, forthcoming, Chapter 6). Conversely, individual flocks of 500 sheep are comparable with those of the largest farms in the parish in 1839, when only six farms had flocks of over 300 (and fifteen had flocks of under 200).[[9]](#footnote-9)

Limited data on livestock numbers in the period 1580-1650 can be gleaned from probate inventories, drawn up after the death of a testator. Though these often give merely a valuation of cattle and sheep, sufficient inventories from before 1650 give the numbers of animals to allow tentative conclusions to be drawn. Sixteen inventories from Loweswater, dating between 1579 and 1649, provide information at this level of detail and can be compared with a sample of inventories from Above Derwent township (the Braithwaite/Newlands Valley area) from the later sixteenth century.[[10]](#footnote-10) In both areas, the typical cattle herd consisted of around a dozen beasts, with a core of 4 to 6 cows. Sheep flocks varied greatly in size but the majority were small: around 60% of both samples comprised under 100 sheep. The largest flocks recorded in the sixteen inventories from Loweswater were 180 (inclusive of lambs) (William Iredell, 1580) and 160 (Robert Wilkinson of Park, 1623). The picture is one of small stock-rearing farms: as elsewhere in the Lake District, crops (largely oats) were grown but quantities appear to have been small.

Using such limited data to derive estimates of total stock numbers in Loweswater in the decades around 1600 is problematic. All that can be done is to calculate mean herd and flock sizes and to use the number of holdings as a multiplier. In the early seventeenth century, Loweswater contained many more holdings than in the nineteenth. A survey of manor of Loweswater in 1614 records 48 holdings, a figure almost double the number in the mid-nineteenth century: as elsewhere in the Lake District, the land market had resulted in a gradual process of farm amalgamation.[[11]](#footnote-11) Table II offers a ‘guesstimate’ of total numbers of cattle and sheep in Loweswater in the early seventeenth century, comparing these figures (which must be regarded as highly tentative) with the stock numbers recorded in 1839 and in the National Farm Survey of 1941.[[12]](#footnote-12) Whereas the size of individual cattle herds appears to have increased substantially between the seventeenth century and 1941, reflecting the change to fewer, larger farms, the total number of cattle may have decreased. Conversely, the large rise in mean flock size (see Table III) appears to have resulted in a significant absolute increase in sheep numbers. If any credence can be given to the figures calculated from the small sample of probate inventories, there are thus hints of a shift further towards sheep farming and a reduction in the global numbers of cattle across the seventeenth and eighteenth centuries.

### Table II: Livestock numbers, Loweswater, c. 1600-1941

## Date Holdings Cattle Sheep

*Mean herd: Total Mean flock: Total*

*c*. 1600 48 9.4 450 77 3700

1839 25 no data no data 220 5504

1941 22 16.5 362 226 4977

### Table III: Sheep flock sizes, Loweswater, c. 1600-1941

*Flock size Number of flocks*

*1579-1649 1839 1941*

< 100 12 (75%) 12 (48%) 5 (25%)

100-199 4 (25%) 3 (12%) 5 (25%)

200-299 0 4 (16%) 4 (20%)

300+ 0 6 (24%) 6 (30%)

Totals 16 25 20

It had been intended to attempt a comparison of data at the level of individual farms between the ‘snapshots’ of *c*.1600, 1839 and 1941, but this has not proved feasible: ensuring the validity of comparisons is made difficult by changes in farm size, notably as a result of farm amalgamation, a process which gathered pace in the nineteenth and twentieth centuries. In no case has it proved possible to be confident that a holding recorded in one source represents the same area of land for which data are available in one of the other ‘snapshots’.

**3. Palaeolimnological records of nutrient change**

***3.1 Background***

A palaeolimnological study of Loweswater was undertaken for the Environment Agency on a sediment core collected in 1999 (Bennion *et al*., 2000a). The aim of the project was to assess the timing and extent of eutrophication. The study arose from concerns about the deteriorating water quality of Loweswater and particularly the occurrence of year round algal blooms, with blue-green algae dominating in recent years. The project involved analysis of the diatom remains *(Bacillariophyceae*: single celled, siliceous algae) in 25 samples from the core, as well as geochemical analysis to determine changes in chemical composition. The core was dated using radiometric techniques, principally 210Pb and 137Cs. Additionally an existing model was applied to the diatom data to infer past total phosphorus (TP) concentrations for the lake. Details of the core and analytical methods are given in Bennion *et al*. (2000a).

***3.2 Evidence of eutrophication***

Loweswater is naturally more fertile than many of the other lakes in the English Lake District because of its relatively lowland catchment with well developed soils (Pearsall, 1921). Nevertheless, the palaeoecological study provided clear evidence of enrichment (Figure III). According to the changes in the diatom assemblages, the onset of enrichment occurred at around 1850 AD with a further increase in productivity since the 1950s. This was in good agreement with the geochemical record which also provided evidence of enrichment over this time period.

Prior to around 1850, the diatom assemblages were typical of relatively nutrient-poor waters, containing many taxa commonly observed in oligotrophic systems, such as those in Wastwater (Bennion *et al.*, 2000b), several Scottish lochs (Bennion *et al*., 2004) and pre-Alpine European lakes (e.g. Wunsam & Schmidt, 1995). A number of taxa indicative of intermediate nutrient concentrations started to increase from the mid-1800s but the most pronounced floristic changes occurred from the 1950s with the expansion of *Tabellaria flocculosa* and *Cyclotella radiosa,* and the appearance of *Fragilaria crotonensis*. Numerous palaeolimnological studies from lakes in Europe and the United States have demonstrated the gradual replacement of the small *Cyclotella* spp*.* by *Aulacoseira* spp., *Tabellaria flocculosa* or *Fragilaria crotonensis* as the process of nutrient enrichment takes place (e.g. Bradbury, 1975; Battarbee, 1978; Bennion, 1994; Anderson, 1997).

The diatom model applied to the data in the original study by Bennion *et al.* (2000a) was based on a dataset of only 46 lakes. Since then an improved training set of 56 relatively large, deep lakes (> 10 m maximum depth) from Scotland, Northern Ireland, Cumbria, southern Norway and central Europe has been developed. The training set has annual mean TP concentrations ranging from 1-73 µg TP L-1 and a median value of 22 µg TP L-1 (Bennion *et al*., 2004). The best model was generated with simple weighted averaging and inverse deshrinking (ter Braak & van Dam, 1989). The coefficient of determination (r2) between observed and inferred values was 0.75 and the root mean squared error of prediction (RMSEP based on the jack-knifing cross validation method) was 0.25 log10 µg TP L-1. This new model has better performance statistics than the 46 lake model and hence in the current project it was applied to the Loweswater diatom data, using C2 (Juggins, 2003). The diatom-inferred TP (DI-TP) reconstruction largely supports the enrichment process inferred from an ecological interpretation of the species shifts in the core (Figure III). The DI-TP values at the bottom of the core were *c.* 10 µg TP L-1, increasing to *c.* 15 µg TP L-1 in Zone 2 and then increasingly a little further and stabilising at *c.* 16 µg TP L-1 in Zone 3. The lower DI-TP values of 13 µg TP L-1 estimated for the uppermost samples are likely to be an artefact of the surface sediment whereby recently blooming taxa have yet to be fully incorporated into the sediment.

The timing of the increase in sediment accumulation rates, based on the radiometric dating results, is coincident with the change in the diatom assemblages. The 210Pb profile suggested a steady acceleration in sediment accumulation rates since the 1950s, following a long period of more uniform accumulation dating back to the late nineteenth century (an increase from 0.08to 0.43cmyr-1). This increase could be due to a combination of allochthonous inputs from the catchment such as soil inwash and agricultural runoff, and autochthonous sources of sedimentary organic matter from algal production.

The palaeoecological findings are supported by historical records of changes in nutrient concentrations. Lambert (1991) reviewed the nitrate data for Loweswater and reported that the values recorded by Carrick & Sutcliffe (1982) in 1955-56 were higher than those measured by Pearsall (1930) in 1928. When Sutcliffe *et al.* (1982) compared their 1970s nitrate data for Loweswater with those from 1955-56 they concluded that there had been a threefold increase in mean nitrate concentrations from 9 to 30 µeq L-1 over this period. In a later survey by Sutcliffe (1998), mean nitrate concentrations had increased still further to 40 µeq L-1. Therefore, there is evidence of a long term increase in nitrate concentrations in Loweswater, starting in around the mid-1900s and continuing to the present day. Lund (1972) reported a tenfold increase in the use of nitrogen fertilisers in the region between the 1950s and 1970s although no specific data were given for the Loweswater catchment. He postulated that this could explain the rise in nitrate nitrogen in Cumbrian lake waters. Whilst there are insufficient data to examine long term trends in P, a comparison of the patchy available data with recent data indicated that TP concentrations have increased slightly in recent decades. For instance, Jones *et al*. (1979) and Sutcliffe *et al*. (1982) recorded mean TP values of 7-8 µg TP L-1, and a survey by Lambert (1991) during summer 1991 recorded TP and SRP concentrations at or below the detection limit of 10 µg L-1. However, in the Environment Agency dataset for 1998-2000, TP had exceeded 20 µg TP L-1 on a number of occasions. Similarly, the annual mean chlorophyll *a* values of *c.* 12 µg L-1 in 1997-1998 were higher than those recorded by Lambert (1991) (0.4 to 3.6 µg L-1) or by Jones *et al*. (1979) (mean 6.8 µg L-1). Furthermore, a comparison of the Secchi disk results for 1997 (minimum=1.2 m, mean=2.9 m), with those of Lambert (1991) who recorded a Secchi depth measurement of 3.5 m on 8/8/1991, indicates a deterioration in light penetration.

Bennion *et al*. (2000a) were not able to establish the causes of the inferred enrichment owing to the limited availability of documentary data on land-use changes and historical events in the catchment to aid interpretation of the findings. They concluded that further information on agricultural statistics was required to interpret the links between changes in land-cover and land management and eutrophication with any confidence. The current project has produced the data needed to make such a link and the following section focuses on a comparison of the historical land-use records with the palaeoecological evidence for changes in productivity over the last few centuries.

Figure III Summary diatom diagram and diatom-inferred total phosphorus (DI-TP) reconstruction for Loweswater

(modified from Bennion *et al*., 2000a)

lowes_new_plot_Apr2010

4. Linking historical land-use change with palaeolimnological records of nutrient change

***4.1 Enrichment in the mid-nineteenth century***

Prior to around 1850, the diatom assemblages of Loweswater were typical of relatively nutrient-poor waters, containing many taxa commonly observed in oligotrophic systems. Land-use statistics indicate that from *c.* 1600 to the mid-1800s activities in the catchment were low intensity with small stock-rearing farms, predominantly sheep with some cattle, and small quantities of crops. Consequently, nutrient loads to the lake were likely to be low in this period. However, a number of taxa indicative of more productive waters started to increase from the mid-1800s. A comparison of the Loweswater data with those from Bassenthwaite Lake and Esthwaite Water (Bennion *et al*., 2000b), and Windermere South Basin (Sabater & Haworth, 1995) shows that changes were first observed in the diatom assemblages of all four lakes from the mid-1800s. The coincident timing of these changes most likely marks the impact of the Industrial and Agricultural Revolutions upon the land-use in the district.

Identifying more precisely the land use changes which may have contributed to this phase of nutrient enrichment in the mid-nineteenth century is made difficult both by uncertainty in the precise chronology of change in the diatom assemblage (nutrient enrichment is dated to 1850 ± 30 years, giving a date range of between 1830 and 1880) and the paucity of land-use data specific to the Loweswater catchment prior to 1866. However, the early/mid-nineteenth century witnessed significant changes in farming technique in Cumbria, in which Loweswater very probably shared, even though it was a parish of small proprietors, rather than being dominated by an ‘improving’ landlord.

Most significant was the spread of field drainage, which gathered pace in the 1820s and 1830s as tile drains became readily available. The number of tileries in Cumberland rose from 36 in the late 1830s to 42 in 1851. Initially, ‘horseshoe’ drains (sheets of clay folded into the profile of a horseshoe and laid on a slate base) were common but from the mid 1840s a revolution in manufacturing technique, whereby pipe drains were extruded mechanically, combined with the introduction of government loans encouraging field drainage, led to a rapid increase in field under-drainage (Davis, 2002). Although the scale and chronology of drainage in the Loweswater catchment has not been established, it is known that there was a local tilery nearby at Mosser in the 1840s and fragments of horseshoe drainage tiles have been found in modern drainage excavations.[[13]](#footnote-13)

Attempts to improve land drainage were accompanied at this period by a drive to ‘sweeten’ the soil by applying lime. Artificial fertilizers were probably uncommon in an area of low capital farming, such as Loweswater, until later in the nineteenth century and lime was probably the main external input. Liming is recorded locally from the mid-eighteenth century: Isaac Fletcher of Underwood, Mosser, built a limekiln at Pardshaw Crag in 1759 and, though production was small in scale, regularly burnt lime for his own use and for sale to neighbouring farmers across the 1760s and 1770s (Winchester, 1994). Small-scale agricultural lime burning became widespread in the first half of the nineteenth century. Loweswater’s proximity to the limestone outcrops in the Eaglesfield and Pardshaw areas would have provided ready access to this important soil improver.

The spread of field drainage and the use of lime would have enabled more intensive use of land that was formerly poorly drained, increasing grass yield (and thus hay to keep livestock over winter) and allowing an increase in the acreage under crops. It seems likely that agricultural productivity in Loweswater increased across the middle decades of the nineteenth century and that this, coupled with an increase in run-off from field drains, may lie behind the nutrient enrichment of the lake at this period.

Loweswater exhibited very little change in diatom composition throughout the first half of the twentieth century, the next point of major change occurring from the 1950s.

***4.2 Enrichment in the mid-twentieth century***

The marked shift in the diatom assemblages in *c.* 1950 towards taxa typically associated with higher nutrient concentrations than those present in the lower section of the core is coincident with major changes in land-use in the Loweswater catchment. In terms of crops, there was a pronounced decline in oat acreage and a lesser decline in root crops from *c.* 1955 which was paralleled by an increase in the acreage of improved grassland and increases in cattle and sheep numbers. The mid-1950s, therefore, marks a period of significant land-use change with a decline in cultivation and an increase in livestock production. The more intensive use of land for pasture also brought with it increased use of chemical fertilisers. The livestock waste and phosphorus- and nitrogen-rich fertilisers would result in higher nutrient loads to the lake. Given the absence of sewage treatment works in the Loweswater catchment and the low population being served by septic tanks, it is reasonable to assume that the pronounced changes in agriculture in the catchment were responsible for the ecological shifts observed in the sediment record. Furthermore, the palaeoecological study indicated that sediment accumulation rates had increased steadily since the 1950s. It is possible that increased sedimentation was associated with intensified modern field drainage although in the absence of any local data this explanation remains entirely speculative. Enhanced algal production arising from the higher nutrient concentrations in the lake may also have contributed to the increase in sediment accumulation rates.

**5. Conclusion**

The study has shown that there is a strong relationship between the timing of nutrient enrichment in Loweswater recorded by palaeoecological methods and changing patterns of land use recorded in historical sources. The close association between the land use changes in the mid-nineteenth (spread of field drainage, use of lime, intensification of land use) and the mid-twentieth (increase in the acreage of improved grassland, increases in livestock numbers, use of artificial fertilisers) centuries with the two periods of major change in the diatom record indicates that changes in agriculture in the Loweswater catchment over the last 200 years have contributed to the nutrient enrichment of the lake. The study demonstrates the value of combining palaeoecological and historical records for improving our understanding of the drivers of environmental change in lake catchments. We hope that these findings can be used to inform future management of the catchment.

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**References**

Anderson, N.J. (1997) Reconstructing historical phosphorus concentrations in rural lakes using diatom models. *Phosphorus Losses from Soil to Water* (edsH. Tunney, O.T. Carton, P.C. Brookes & A.E. Johnstone). Cab International, pp. 95-118.

Battarbee, R.W. (1978) Observations on the recent history of Lough Neagh and its drainage basin. *Philosophical Transactions of the Royal Society of London,* 281, 303-345.

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

Bennion, H., Appleby, P., Boyle, J., Carvalho, L., Luckes, S. & Henderson, A.. (2000a). *Water quality investigation of Loweswater, Cumbria*. Final Report to the Environment Agency by the Environmental Change Research Centre, University College London: pp 80.

Bennion, H., Monteith, D. & Appleby, P. (2000b). Temporal and geographical variation in lake trophic status in the English Lake District: evidence from (sub)fossil diatoms and aquatic macrophytes. *Freshwater Biology,* 45, 394-412.

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

Bradbury, J.P. (1975) Diatom stratigraphy and human settlement in Minnesota. *Geological Society of America Special Paper,* 171, 1-74.

Carrick, T.R. & Sutcliffe, D.W. (1982) Concentrations of major ions in lakes and tarns of the English Lake District (1953-1978). *Occasional Publications*, 16. Freshwater Biological Association, pp 170.

Davis, E. (2002) Clay drainage tile and pipe manufacture at Johnby Wythes, Greystoke c. 1851-1909. *Transactions of Cumberland & Westmorland Antiquarian & Archaeological Society*, 3rd ser. 2, 261-75

Jones, J.G., Orlandi, M.J.L.G. & Simon, B.M. (1979) A microbiological study of sediments from the Cumbrian lakes. *Journal of General Microbiology*, 115, 37-48.

Juggins, S. (2003).C2 User guide. Software for ecological and palaeoecological data analysis and visualisation. University of Newcastle, Newcastle upon Tyne, UK, 69 pp.

Lambert, J.E. (1991) Cyanobacteria (blue-green algae) in Loweswater: A literature review and report on original work. Unpublished MSc thesis, University of London.

Lund, J.W.G. (1972) Eutrophication. *Proc. R. Soc. Lond.* *B*, 180, 371-382.

Marks, H. F. and Britton, D. K. (1989). *A Hundred Years of British Food and Farming: a statistical survey* (London: Taylor & Francis).

Pearsall, W.H. (1921) The development of vegetation in the English Lakes, considered in relation to the general evolution of glacial lakes and rock basins. *Proceedings of the Royal Society of London B,* 92, 259-284.

Pearsall, W.H. (1930) Phytoplankton in the English lakes. I The proportions in the waters of some dissolved substances of biological importance. *Journal of Ecology*, 18, 306-320.

Rodgers, C. P., Straughton, E. A., Winchester, A. J. L. and Pieraccini, M. (forthcoming). *Contested Common Land: environmental governance, past and present* (London: Earthscan).

Sabater, S. & Haworth, E.Y. (1995) An assessment of recent trophic changes in Windermere South Basin (England) based on diatom remains and fossil pigments. *Journal of Paleolimnology*, 14, 151-163.

Searle, C. E. (1993). Customary tenants and the enclosure of the Cumbrian commons. *Northern History* 29, 126-53.

Sutcliffe, D.W., Carrick, T.R., Heron, J., Rigg, E., Talling, J.F., Woof, C. & Lund, J.W.G. (1982) Long-term and seasonal changes in the chemical composition of precipitation and surface waters of lake and tarns in the English Lake District. *Freshwater Biology*, 12, 451-506.

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

Whetham, E. H. (1978). *The Agrarian History of England and Wales Volume VIII, 1914-1939* (Cambridge: Cambridge University Press).

Winchester, A. J. L. (ed.) (1994). *The Diary of Isaac Fletcher of Underwood, Cumberland, 1756-1781* (Kendal: Cumberland & Westmorland Antiquarian & Archaeological Society Extra Series XXVII).

Winchester, A. J. L. (2000). *The Harvest of the Hills: rural life in northern England and the Scottish borders 1400-1700* (Edinburgh: Edinburgh University Press).

Winchester, A. J. L. with Wane, M. (eds.) (2003). *Thomas Denton: a Perambulation of Cumberland 1687-*8 (Surtees Society Vol. 207).

Wunsam, S. & Schmidt, R. (1995) A diatom-phosphorus transfer function for Alpine and pre-alpine lakes. *Memorie dell’Istituto Italiano di Idrobiologia,* 53, 85-99.

**Appendix I: Loweswater: acreage under crops 1866-1988 (5-year means)**

Years Wheat Barley Oats Potatoes Turnips

1866-9\* 17.7 16.8 161.9 39.3 60

1870-4\* 20.5 9.5 168 41 60

1875-9\* 16.8 2.5 172.2 39.3 52.3

1880-4 10 8.75 179.7 39.3 65.3

1885-9 6.75 7.95 192.6 41.8 68

1890-4\* 3.7 4.7 187.2 32.2 67.2

1895-9 2.3 3.5 162 28.4 57.6

1900-4 0.7 0 168.1 28.1 59.4

1905-9 0 0.6 163.1 27.1 62.3

1910-4 1.0 1.2 155.8 25.3 63.9

1915-9 3.4 2.3 201.8 30.8 61.6

1920-4 1.0 4.9 149 38 61.5

1925-9\* 0 2.6 133.7 27.8 48.2

1930-4 0 0 113.7 22.1 44.6

1935-9 0 0 101.5 15.4\* 46.1\*

1940-4 1.2 3.7 195.1 34.4\* 46.6\*

1945-9\* 3.5 1.1 179.3 38.7 53.3

1950-4 2.8 0.4 149.4 22.3 51.9

1955-9 0 0 94.5 8 35.2

1960-4 0 13.4 62.9 6.3 28.4

1965-9 0.6 24.1 8.4 2.6\* 21\*

1970-4 0 31.1 2.0 11.4\* 16.9\*

1975-9 0 23 4.4 3\* 9.7\*

1980-4 0 18.9 0 \* \*

1985-8 0 9.7 0 \* \*

# Quarter-century means

1866-74 19.1 13.2 165 40.2 60

1875-99 7.9 5.5 178.7 36.2 62.1

1900-24 1.2 1.8 167.6 29.9 61.7

1925-49 0.9 1.4 144.7 27.7 47.8

1950-75 0.7 13.8 63.4 10.1 30.7

1975-88 0 17.2 1.5 \* \*

\* = incomplete data (years missing)

**Appendix II: Loweswater: Livestock Numbers 1866-1988 (5-year means)**

Cattle Sheep

Years Cows/H Others Total %Cows Sheep Lambs Total

1866-9\* 190 331 521 35 2811 1298 4109

1870-4\* 180 406 586 31 3452 2153 5605

1875-9\* 174 383 557 31 3864 2481 6345

1880-4 182 352 534 34 3566 2292 5858

1885-9 228 445 673 34 3891 2615 6506

1890-4\* 259 474 733 35 4616 2963 7579

1895-9 265 470 735 36 5156 2937 8093

1900-4 226 476 702 32 4590 2833 7423

1905-9 228 478 706 32 4319 2826 6965

1910-4 230 443 673 34 4441 2922 7363

1915-9 245 456 701 35 3923 2633 6556

1920-4 242 418 660 37 3931 2645 6576

1925-9\* 245 410 655 37 4071 2916 6987

1930-4 244 390 634 38 4280 2704 6984

1935-9 247 355 602 41 3773 2714 6487

1940-4 298 371 669 45 4069 2639 6708

1945-9\* 382 440 822 46 4304 2350 6654

1950-4 400 423 823 49 5405 2600 8005

1955-9 402 380 782 51 4829 3025 7854

1960-4 490 498 988 50 5271 3461 8732

1965-9 607 609 1216 50 5187 3356 8543

1970-4 647 864 1511 43 4822 3219 8041

1975-9 808 696 1504 54 4681 3237 7918

1980-4 845 720 1565 54 6012 4869 10881

1985-8 793 804 1597 50 6844 6010 12854

# Quarter-century means

1866-74 185 367 552 3132 1726 4858

1875-99 222 425 647 4219 2658 7877

1900-24 234 454 688 4241 2772 7013

1925-49 283 393 676 4099 2665 6764

1950-74 509 555 1064 5103 3132 8235

1975-88 815 740 1555 5846 4705 10551

Notes:

\* = incomplete data (years missing)

Cows/H = Cows and heifers

%Cows = Cows and heifers as percentage of total cattle herd.

1. We should like to record our thanks to Dr Sarah Rose, who gathered the bulk of the archival material on which this report is based, capturing and sorting data from records in The National Archives (Kew) and the Lancashire and Cumbria county record offices. [↑](#footnote-ref-1)
2. The grassland acreages given in the returns may need to be treated with caution, as the total acreage of ‘crops and grass’ plus ‘rough grazing’ fluctuates widely from year to year; in 1945 it was 6,904 acres; in 1950: 7,496 acres; in 1955: 7,478 acres; in 1960: 6,591 acres; in 1965: 7,745 acres. Since the returns were made by each agricultural holding, it is likely that the proportion of land in the parish covered by the returns varied from year to year, as land forming part of a farm in Loweswater but lying outside the parish would be included in the return and land in Loweswater attached to farms outside the parish would be returned elsewhere. [↑](#footnote-ref-2)
3. Information from Mr John Clark, Eaglesfield (2010). [↑](#footnote-ref-3)
4. The National Archives (Kew), MAF 32/184/105. [↑](#footnote-ref-4)
5. Cumbria Record Office, DB 72/2. [↑](#footnote-ref-5)
6. Information from Mr John Clark, Eaglesfield (formerly of Mossergate) (2010). [↑](#footnote-ref-6)
7. Cumbria Record Office, D/Law, rough survey of estates in Loweswater, 13 Apr. 1691; memorandum ‘What I have in Lowswater’, 1693. [↑](#footnote-ref-7)
8. The National Archives, IR 18/694 (Loweswater tithe file, 1839). [↑](#footnote-ref-8)
9. The National Archives, IR 18/694 (Loweswater tithe file, 1839). [↑](#footnote-ref-9)
10. The Loweswater inventories are in Lancashire Record Office, WRW (C) (Copeland deanery probate records). For the data from Above Derwent, see Winchester, 2000, pp. 18-21. [↑](#footnote-ref-10)
11. Cumbria Record Office, D/Law/1/248 (survey, 1614) compared with The National Archives, IR 18/694 (holdings listed in Loweswater tithe file, 1839, excluding those in Mockerkin and Sosgill). [↑](#footnote-ref-11)
12. Data for 1839 from The National Archives, IR 18/694; data for 1941 from MAF 32/184/105. [↑](#footnote-ref-12)
13. The tilery near Aikbank Mill is recorded in the Mosser tithe plan of 1840: Cumbria Record Office, DRC/8/134. [↑](#footnote-ref-13)