Sediment Sourcing and Environmental Reconstruction Using Particle Size-Specific Magnetic Fingerprinting: Bassenthwaite Lake, UK

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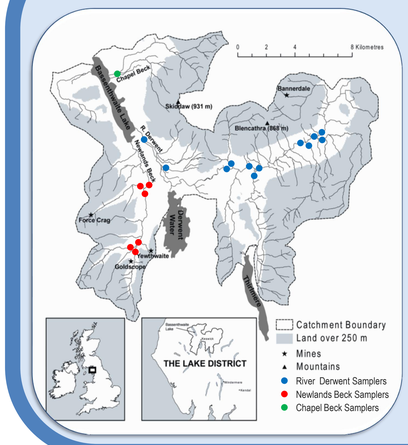
1. Introduction

Bassenthwaite Lake is a typical example of a temperate upland environment currently suffering problems of eutrophication and water quality degradation associated with increased delivery of fine sediment. For successful management and mitigation of these issues, identification of the sources of this increased sediment loading is a key requirement. Magnetic measurements have been shown to be highly discriminatory in a range of environments (e.g. Walling et al., 1979; Yu and Oldfield, 1993) and sediment fingerprinting is potentially the most discriminatory method linking sediment mobilisation and delivery (Collins and Walling, 2004). However, despite magnetic measurements (and other parameters) often displaying strong particle size dependence, few workers perform analysis on a particle size specific basis. Thus, great potential exists for increasing their discriminatory power by using particle size specific magnetic fingerprinting.

2. Site Description



Bassenthwaite Lake in the English Lake District, UK is a designated SSSI and contains a rare protected fish, the vendace. The lake`s 240 km^2 catchment can be divided into three main subcatchments. The River Derwent (provides 80 % of the hydraulic loading), Newlands Beck (providing 10 %) and minor inflows, dominated by Chapel Beck (providing the final 10 %). Land use is dominated by pastoral farming practices in the valley bottoms, whilst open moorland dominates the valley sides and tops. The Derwent Valley has a long history of occupation and is assumed to provide the majority of the sediment to the lake, in contrast the Newlands ('new lands') Valley was occupied much later (*c.* 300 yrs ago) but experiences greater land use pressures.

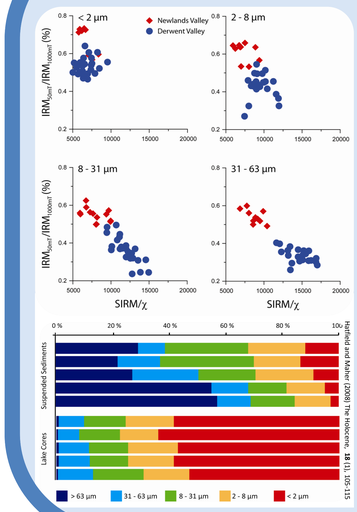
3. Methodology

Nineteen time integrated suspended sediment samplers (Phillips et al., 2000) were deployed in the catchment with monthly collection for ~ 2 years (see left and map above). Six one-meter (BASS 1-6) and two three-meter (BASS 8 & 9)cores were taken from the lake for comparison with the suspended sediments.

Upon return to the laboratory samples were separated into 5 particle size fractions; > 63 µm (by sieving), 31 - 63 µm, 8 - 31 µm, 2 - 8 µm and < 2 µm (by settling in Atterberg columns). Magnetic measurements included magnetic susceptibility, ARM and IRM expressed on a mass normalised basis; combinations of these parameters allowed calculation of a number of concentration independent ratios.

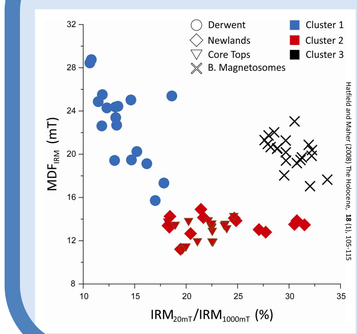
Fuzzy clustering, a multivariate classification technique, was used to group similar and discriminate between samples, allowing subcatchment contributions to Bassenthwaite Lake to be quantitatively examined.

4. Particle Size Dependence



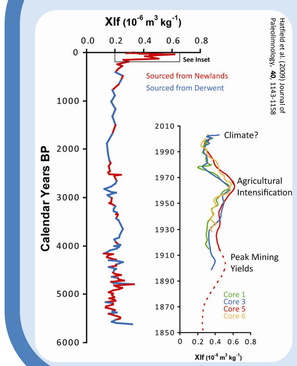
Magnetic properties of the suspended sediments and lake sediments show strong particle size dependence. For example, coarser fractions possess higher SIRM/χ and lower IRM_{50mT}/IRM_{1000mT} values than finer fractions (a). This is important for tracing given the differences in the modal particle size distributions; sand for the suspended load and clay for the cores (b). Thus, source unmixing should only be attempted on a particle size specific basis. Consultation of the four particle sizes (a) also shows that the 31 - 63 µm fraction provides greatest discrimination between potential sources, whereas discrimination between the < 2 µm and 2 - 8 µm fractions is less distinct.

5. Contemporary Source Matching



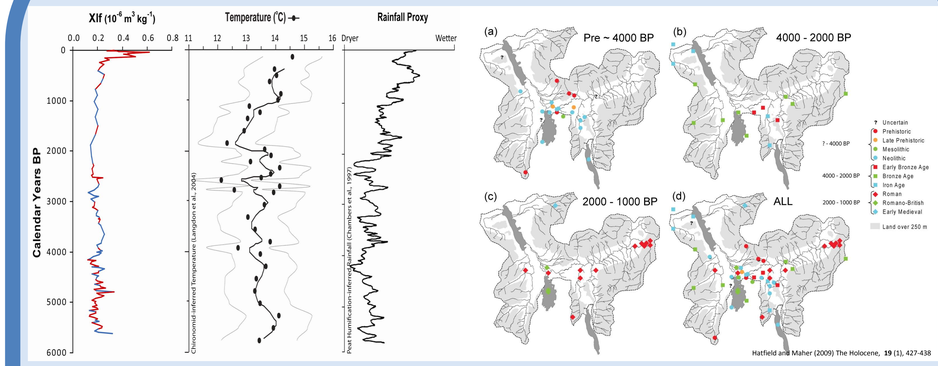
Comparing 'core top' sediments (top 10cm) from the 6 1-meter cores to the suspended sediments from the sub catchments allows identification of the major sources of lake sediment. Fuzzy clustering quantitatively discriminates between the two main inflows and any authigenic bacterial magnetosomes. The most recent lake sediments are strongly affiliated (>>80 %) with the material transported within Newlands Beck. This is surprising as it only provides 10 % of the hydraulic load

6. Historical Source Matching



Magnetic susceptibility is often used as an erosion proxy. Here recent increases in sediment flux appear to be associated with Newlands sources, superimposed on a relatively low and constant Derwent flux, with unprecedented delivery of sediment in the last 200 years. Cores show similarity in properties suggesting efficient sediment redistribution patterns. Increases in sediment flux from the catchment appear associated with specific catchment changes; mining in the late 19th century, agricultural intensification during the 1960's and possibly increased climate seasonality post 1990.

7. Human & Climate Influences



The magnetic susceptibly record appears insensitive to temperature and rainfall climate changes throughout the late Holocene until the large shift ~200 years ago. Early human activity is concentrated in the valley bottoms around the lakes, Roman occupation 2000 years ago lead to expansion up the Derwent Valley; the Newlands ('new lands') valley was not occupied until much later. However, like climate shifts these significant land use changes did not increase sediment flux during the mid-late Holocene. Mining has a significant history in the Bassenthwaite catchment from the 17th century, peaking towards the end of the 19th century, concentrated in the Newlands Valley. Here significant land use change, coupled with extensive channel engineering of the lower portions of Newlands Beck appear to be responsible for the 3 fold increases in sediment flux to Bassenthwaite Lake.

8. Discussion

Evidence from these multiproxy records indicates a stepwise increase in human impacts on sediment dynamics in the Bassenthwaite catchment only within the last 150-200 years, despite archaeological (and pollen) evidence for human activity and occupation through the last ~ 5.5 kyrs. Either this activity was insufficient to alter catchment sediment dynamics and/or sediment storage and redistribution has until recently 'buffered' sediment influx to the deep lake basin. Any such buffers appear to have been exceeded by recent, intense land use and river channel changes in the Newlands catchment. The combination of increased sediment supply and decreased sediment storage (on floodplains and in channels) has resulted in rapid and ongoing acceleration of sediment influx to the lake. Given predictions and observations of increased rainfall and storm intensity linked to global warming, the ecological status of Lake Bassenthwaite, is likely to deteriorate further and rapidly, unless accelerated sediment supply is mitigated and sediment storage capacity restored.

9. Conclusions

- Magnetic properties of lake and suspended sediments are particle size-dependent; analysis on a particle size- specific basis is required to compare 'like with like' and avoid *in situ* authigenic effects
- A few select magnetic measurements can describe both sediment source and sediment flux effectively
- Magnetic measurements coupled with fuzzy clustering can be used to trace sediment sources on a quantitative basis, in a range of situations and over a range of timescales
- >>80% of the contemporary sediment sourced from Newlands Beck (10% of the hydraulic load)
- Accelerated sediment flux is a very recent (last 300 yrs) phenomenon, in response to specific land use changes in the Newlands catchment. Before this flux was generally low & sourced through the Derwent.
- Sediment storage processes have been important in restricting sediment (especially that sourced through the Derwent) to the lake's deep basin throughout most of the Holocene.
- Increasing land use intensity and pressure has decreased sediment storage and increased sediment supply, leading to greater sensitivity to changing climate intensity and seasonality