Project no. GOCE-CT-2003-505540

Project acronym: Euro-limpacs

Project full name: Integrated Project to evaluate the Impacts of Global Change on European Freshwater Ecosystems

Instrument type: Integrated Project

Priority name: Sustainable Development

---

Deliverable No. 158

DOC mediated light distribution in the Round Loch of Glenhead: an evaluation of the use of epipelic diatoms as indicators of changing concentrations of DOC

Due date of deliverable: Month 42
Actual submission date: Month 60

Start date of project: 1 February 2004
Duration: 5 Years

Organisation name of lead contractor for this deliverable: UCL

Revision FINAL

---

<table>
<thead>
<tr>
<th>Dissemination Level (tick appropriate box)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
</tr>
<tr>
<td>PP</td>
</tr>
<tr>
<td>RE</td>
</tr>
<tr>
<td>CO</td>
</tr>
</tbody>
</table>
1. Introduction

Long-term monitoring data in the UK and elsewhere in Europe show that DOC concentrations in upland surface waters have been steadily increasing over the last two decades. Whilst initial hypotheses focused on the effects of global warming (Freeman et al., 2001), Monteith et al. (2007) have shown that a factor explaining a large part of the variance in the trend is the decrease in non-marine sulphate concentration that has occurred following controls on S emissions across Europe. If this explanation is correct DOC levels may be returning towards background pre-acidification reference conditions rather than towards unprecedented higher values as might be expected from the global warming hypothesis.

In principle these two alternative explanations can be tested by reconstructing past DOC concentrations from dated lake sediment cores. As yet, however, there is no established robust palaeolimnological method that allows DOC to be reconstructed confidently. The standard method uses diatom-DOC transfer functions (e.g. Birks et al., 1990), but this has not proven to be a robust method as the stronger influence of lake water pH in controlling diatom composition can confound the DOC-diatom relationship. Alternative approaches include: (i) the use of near-infrared spectrometry (NIRS), a technique being developed primarily in Sweden by Rosen et al. (2005) to infer DOC based on a transfer function approach; and (ii) the use of changes in the abundance of epipelic diatoms in sediment cores as indicators of DOC-mediated changing light climate attempted here for the Round Loch of Glenhead.

This last approach assumes that the epipelic diatom flora in lakes can be uniquely characterised and that the abundance of the epipelon (or in effect the size of the epipelic habitat) is controlled by light penetration that is in turn controlled by water column DOC concentration. In sites with relatively low slope gradients between the littoral and profundal zones of a lake, the size of the epipelic habitat (and epipelic productivity) should vary strongly with DOC concentration and the varying proportions of epipelic diatoms in sediment cores might then be used as a past proxy for DOC.
2. DOC – light relationships for UK upland lakes

Thirty upland oligotrophic lakes in Wales and Scotland were surveyed during 2004 and 2005. Detailed bathymetric surveys were conducted and a LICOR LI-193 Underwater Spherical Quantum Sensor was used in a deep water location from an inflatable boat to determine the photosynthetically active radiation (PAR) attenuation coefficient. Water chemistry samples were also taken and analysed for DOC and absorbance at a range of wavelengths between 254 and 400 nm.

Light profiling demonstrated that DOC concentration exerted a very tight control on PAR penetration and revealed a highly consistent relationship between DOC concentration and the PAR attenuation coefficient across the sites (Figure 1). The findings indicated that large increases in DOC concentration (as identified by the UK AWMN) should have resulted in a marked shift in the distribution of PAR with depth (Figure 2). Hence, light availability is inferred to have diminished across key benthic diatom habitats within DOC-dominated lakes. Importantly, therefore, the surface area of the epipelic habitat illuminated to a level of >1% incident light should have contracted significantly in lakes where DOC concentrations have risen.

![Figure 1: Relationship between DOC concentration and the PAR attenuation coefficient for the 27 lakes in the Euro-limpacs survey that were sufficiently deep to record a full light profile.](image-url)
Figure 2: Relationship between DOC concentration for the 27 Euro-limpacs lakes and modelled depth of 1% PAR surface irradiance based on linear regression equation in Figure 1. Red line represents modelled profile for all lakes. Typically DOC concentrations have approximately doubled in upland lakes in the UK over the past two decades. Larger reductions in light penetration would be expected to have occurred in lakes with lower initial DOC concentrations.

3. Epipelic diatom populations as DOC indicators

To evaluate the use of epipelic diatom populations as indicators of changing DOC using the light-DOC relationship above we have carried out a detailed study of the epipelic diatom flora of the Round Loch of Glenhead, an acidified, upland loch in Galloway, South-west Scotland. The loch is one of the most studied acid lakes in the UK. It is part of the UK Acid Waters Monitoring Network and a number of previous diatom studies have been conducted at the site (e.g. Flower and Battarbee, 1983; Jones, 1987; Flower et al., 1988; Jones et al., 1989; Allott et al., 1992). However, the epipelic flora itself has never been specifically examined. Monitoring data since 1988 have shown that DOC concentrations have approximately doubled from ca. 2.5 mg/l to ca. 5 mg/l in 2006 (Shilland et al., 2006, and Figure 3). We hypothesise here that the reduction in transparency caused by the increase in DOC would have restricted the habitat available for epipelic diatoms.

Our objectives therefore were: (i) to identify which diatoms could be regarded as indicators of the epipelon from the analysis of samples of surface sediment from the loch taken at different water depths; and (ii) to use the results to reconstruct changes in the abundance of epipelic diatoms (and thereby changes in DOC), from the diatom record of the lake sediment.
4. Field methods to sample diatoms from the different habitats in the lake

Two sampling approaches were used: (i) repeated sampling along a fixed transect from the shore to deep water; and (ii) surface sediment sampling across the whole basin. The location of the fixed transect is shown in Figure 4. A 80-m rope was fastened to a permanent stake on the shoreline and extended to an anchored buoy at a water depth of approximately 10 m. Surface sediment samples were collected along the transect at 0.25 m depth intervals from the surface to 1.5 m, 0.5 m intervals from 1.5 to 6 m and 1 m intervals from 6 to 9 m. The water depths were measured using a tape measure and echo sounder. The distances were measured using a tape measure tied to the rope. Different samplers were used according to the different water depths: a ring and slicer was used to collect samples from 0 to 0.50 m by wading; a self-designed epipelon sampler (Yang and Flower, 2009) was used to collect samples between 0.75 m and 1.25 m from the boat; and a Renberg corer was used to collect samples from 1.50 m and 9.00 m from the boat. The top 1 cm sediment of the cores was sliced off for surface sediment samples. All sediment samples were transported back to the laboratory and stored at 4°C.

Figure 3. DOC concentration in the Round Loch of Glenhead (1988-2006).

Figure 4. Location and map of the Round Loch of Glenhead and the fixed depth transect located in the south of the loch.
Sampling across the lake basin used a stratified method to ensure good areal coverage as well as preserve the advantage of randomness (Watts and Halliwell, 1996). The loch area was divided into 40 × 40 m grids which created 68 cells and GPS positions (OSGB 36) of the centre points of each cell were set up on GARMIN GPS III. In the field, the boat was navigated by the waypoints, and stopped near the centre point. Samples were collected using a Renberg corer in the cell at the point the boat stopped moving. The top 1 cm sediment was sliced off for surface sediment samples. Diatoms from epipsammic, epilithic and epiphytic habitats in the lake were collected using standard techniques (cf. Battarbee et al., 2001).

5. Preparing microscope slides for analysis of the epipelic diatom flora

Surface sediments contain diatoms from a mixture of sources including living motile taxa that form the true epipelon, other living non-motile diatoms found on surface sediments and dead taxa transported and deposited on to the surface sediments from other habitats. To separate these fractions three sets of slides were made from each sample. The first used a modified tissue method (Eaton and Moss, 1966; Yang et al., submitted) to separate the motile fraction, the second a coverslip method to separate live from dead frustules (Cox, 1996) and the third used the standard method for sediments (Renberg, 1990; Battarbee, et al., 2001) to enumerate the total diatom content. Diatoms from epipsammic, epiphytic and epilithic habitats were prepared for microscopy using standard techniques (Battarbee, et al., 2001).

6. Diatoms from surface sediments along the depth transect

6.1 Live motile diatoms

Using the lens tissue technique described above, motile diatoms were counted from samples obtained along the fixed transect shown in Figure 4 on seven different occasions spanning 18 months. The distribution of the dominant taxa plotted against water depth for one example sampling period (July 2007) is shown in Figure 5 together with measurements of Chl a and other variables. A total of 23 motile taxa were observed and the dominant taxa were *Navicula leptostriata* and *Frustulia rhomboides* var. *saxonica*. These species contributed more than 75% of the total diatom abundance and displayed abundance peaks between 1 and 2 m depth.

Figure 5. Environmental variables, selected motile diatom and total motile diatom abundance (cells mm$^{-2}$), Chl a concentration (µg l$^{-1}$), PCA first axis score, Shannon Wiener diversity index ($H'$), and Pielou’s evenness index ($J'$) along the depth transect in July 2007.
6.2. Total live diatoms

In contrast to the number of motile taxa in the sample the total number of living diatom taxa identified was 53. *Navicula leptostriata*, and *Frustulia rhomboides* var. *saxonica* remained dominant but other non-motile dominants included *Tabellaria quadriseptata* and *Eunotia incisa*; together these taxa contributed approximately 75% to the total diatom abundance. The increase in number of taxa is caused by the presence of living, mainly non-motile diatoms derived from other habitats. The distribution in the abundance of live diatoms for the July 2007 transect is shown in Figure 6 together with *Chl a*, live diatom to total diatom ratio, and associated environmental variables.

![Figure 6. Environmental variables, selected live diatom and total live diatom abundance (cells mm⁻²), Chl a concentration (µ g l⁻¹), live/total diatom %, PCA first axis score, Shannon Wiener diversity index (H'), and Pielou's evenness index (J') along the depth transect in July 2007.](image)

6.3 Total diatoms (live and dead)

When both live and dead cells were included in the counts 117 benthic taxa were observed. *Navicula leptostriata*, *Frustulia rhomboides* var. *saxonica*, *Eunotia incisa*, *Tabellaria quadriseptata*, *Eunotia vanheurckii* var. *1*, *Navicula hoefleri*, *Eunotia naegelii*, *Navicula madumensis* and *Achnanthes marginulata* were the dominants and together they contributed approximately 75% of the total diatom abundance. The depth distributions of the main diatoms, *Chl a*, and associated environmental variables along the depth transect for July 2007 are shown in Figure 7.
7. Spatial distribution of live diatoms from profundal surface sediments in the loch

In order to assess the spatial distribution of live diatoms and the extent of the epipelic habitat surface sediment samples were collected and analysed as described above and the distribution of the dominant taxa were mapped using Arc-GIS.

7.1 Live motile diatoms

The dominant motile diatom species *Navicula leptostriata* and *Frustulia rhomboides var. saxonica* mainly appeared in the littoral areas of northwestern and southeastern parts of the loch (Figure 8).

Figure 7. The environmental variables, selected diatoms (valves DW mg$^{-1}$) and total diatom abundance ($10^3$ valves DW mg$^{-1}$), PCA first axis score, Shannon Wiener diversity index ($H'$), and Pielou’s evenness index ($J'$) along the depth transect for July 2007.

Figure 8. Spatial distribution of motile diatom (cells cm$^{-2}$) from fresh surface sediment samples in the Round Loch of Glenhead in April 2007.
7. 2. Live diatoms

Figure 9 shows the distribution pattern in the loch for live diatoms (motile and non-motile). *Tabellaria* spp. occurred around the entire loch but mainly in shallower water. *Navicula leptostriata* appeared mainly in the northeastern part of the loch with *Frustulia rhomboides* var. *saxonica* dominant in the southeastern and southwestern parts. *Eunotia incisa* was present in most areas of the loch but in somewhat higher abundance in the northeastern part.

Figure 9. Spatial distribution of live diatoms (cells mm\(^{-2}\)) from fresh sediment samples in the Round Loch of Glenhead in April 2007.
8. Reconstructing DOC in the Round Loch of Glenhead

Light clearly has a major influence on the distributions of living motile diatoms along a depth transect in the RLGH. However, analysis of the distributions of these diatoms throughout the lake indicates that spatially-related factors also play an important role in controlling these distributions. Work is in progress to develop a statistical method relating the abundance and distribution of the epipelic diatom flora to light and DOC in the Round Loch. The usefulness of the approach to reconstruct DOC from the fossil diatom assemblages of a sediment core from the loch will then be assessed and the results will be compared with the results of DOC reconstruction using other methods, principally the diatom-DOC transfer function of Birks et al. (1990) and the NIRS methods of Rosen et al. (2005). In preparation for this next stage a 35 cm short core was collected from the centre of the loch in October 2007 using a Renberg corer. The sediment was extruded and sliced at 0.25 cm interval from 0 to 3 cm, 0.5 cm interval from 3 to 15 cm and 1 cm intervals from 15 to 35 cm. Diatoms were identified and counted, and dry weight, LOI were also measured. The final results from this study will be presented in Yang Hong’s forthcoming PhD dissertation.

References


