**Institution:** University of Bristol

**Unit of Assessment:** 5 – Biological Sciences

**Title of case study:** UK and Ireland benefit from improved assessment of water quality in rivers and lakes using new diatom-based tools

## 1. Summary of the impact

A team at Bristol University has played a central role in the development of new methods for assessing water quality in rivers and lakes. These are making it possible for the water industry to more reliably assess water quality and identify sites where remedial measures must be applied to meet the new standard of 'good ecological status' as required by the European Union Water Framework Directive (WFD), which passed into UK law in 2003. The innovative, diatom-based tools were used in 2008 and 2009 to assess all targeted surface waters (rivers and lakes) in the UK and Ireland, leading to massive investment in infrastructure. This has opened up the prospect of higher quality water in lakes and rivers – something that the public and environmental organisations demand. Over the next few decades, the investment will bring an estimated benefit of £200 million to residents in England and Wales alone.

## 2. Underpinning research

### Context

Benthic diatoms are abundant and diverse environmental indicators; individual species have an optimum and tolerance for nutrients that can be quantified, making diatom assemblages a powerful tool to quantify environmental change such as gradients of eutrophication. As a result, the Trophic Diatom Index (TDI) has been used as a metric to monitor eutrophication in UK rivers since the mid-1990s. In December 2000, the EU WFD came into force, which, for the first time, prescribed an ecological approach to monitoring freshwater with the aim of achieving 'good ecological status' for all water bodies by 2015. The approach defined by the directive includes the assessment of phytobenthos (diatoms) and macrophytes, among other biological elements, to monitor anthropogenic pressures on freshwater systems. These pressures are expressed as a comparative ratio whereby the observed biology of a system is compared with that expected in a pristine system (Ecological Quality Ratio=Observed/Expected). Contrary to previous non-reference based metrics, these new metrics require a measure of the deviation of the biological condition from that which we would expect to find in a natural or minimally disturbed site, defined as the 'reference condition'. This ratio is then used to classify freshwater systems into one of five status categories: high, good, moderate, poor or bad. To help the UK meet the requirements of the WFD, a group of diatom experts, including Dr Yallop at the University of Bristol, was brought together to develop new predictive, reference-based tools, using diatoms (one for rivers and one for lakes) to be used in the assessment of the ecological status of freshwaters.

### Bristol contributions

Research began in 2002 and the tools were delivered to government agencies in 2007. Dr Marian Yallop, Senior Lecturer in Bristol's School of Biological Sciences (appointed September 1993), together with her research team (a postdoctoral research scientist and a Master's student), provided the taxonomic expertise required to build the database that was central to the development of the diatom tools used to assess the state of UK rivers and lakes [1, 2]. Dr Yallop contributed significantly in terms of data interpretation [3], and drew upon her 30 years of research experience to provide guidance for setting the state class boundaries based on her knowledge of the structure and functioning of benthic biofilms. The Bristol team also:

- led the research that validated the concepts of ideal reference biota for rivers [4];
- collated and processed all new river samples from sites across UK and Northern Ireland;
- designed and co-ordinated the sampling strategy for sample collection and provided statistical interpretation for the data sets required to assess the risk of misclassification of water bodies [5];
- addressed questions relating to the spatial and temporal heterogeneity in the species assemblages; and
- provided taxonomic expertise for building the lake classification tool [6].

### Compiling a reference database for the diatom tools

The new diatom tools offer the first reference-based indices for assessing water quality across the UK. The original TDI, developed for application at sewage treatment works, was refined and expanded to meet the assessment requirements of the WFD, giving a far more comprehensive indication of ecosystem health. The tools can be used for all relevant UK lakes and rivers and

enable measurements of deviation from the flora expected to occur in the absence of impairment. Video material was produced at Bristol, to train and inform Environment Agency (EA)/Scottish Environment Protection Agency (SEPA) staff on correct sampling strategies to ensure comparability across different river basin areas. An extensive database was compiled that correlated species composition of benthic diatoms in rivers (~1,000 river samples) and lakes (~1,200 samples) with site-specific environmental data, and this ultimately formed the basis for the diatom-based tools. This database was then matched to environmental data in order to produce a site-specific reference typology (the expected values) using river sites that were unaffected by anthropogenic influences. The tool-building was undertaken by Dr S. Juggins (Newcastle University), with Yallop providing further data analysis and interpretation. The development of the diatom tools was detailed in a report to the EA [1], as well as two peer-reviewed articles, one for rivers [2] and one for lakes [Bennion et al. (2014), *Freshwater Science*, 33(2), *accepted*].

**Determining the risk of misclassifying the status of a water body**

Yallop devised and co-ordinated new biofilm sampling to quantify the temporal heterogeneity of the diatom assemblages across the ecological status gradient in lakes and rivers in the UK. Inferring status from a limited number of samples presents a risk that the status inferred may be different from the true status. The scale of uncertainty was quantified and guidelines provided for the risk of placing a water body in the wrong ecological status class [5]. She carried out all initial statistical work for this component. Yallop's prior research into the spatial and temporal variability of phytobenthic assemblages in rivers [3] consolidated the team's understanding of biofilm succession and relevance to data interpretation. She also contributed expertise in lake structure and functioning to highlight the constraints in sampling littoral regions of lakes [6]. As water bodies could fall on the border of two ecological status classes, such as good and moderate, the regulatory agencies need to be able to quantify the uncertainty related to status class assessment for individual sites. Armed with this information, they can make informed decisions regarding the need to introduce a Programme of Measures (PoM) where River Basin Management plans are developed identifying the necessary steps required to restore 'good ecological status' for impaired rivers and lakes.

**Using historical information to validate values for expected 'pristine' reference conditions**

Further, Yallop and her Bristol team led the research to validate the concept of 'pristine' conditions by collecting and identifying historical diatom samples from herbarium collections and comparing them to present day samples of river diatoms from matching locations [4].

**Training of agency staff and non-academic outputs of the research**

Dr Yallop is one of the original team of six experts in the UK who set the benchmark for taxonomic standards for analysis of diatom samples used to assess water quality in rivers across the UK. She has trained EA/SEPA staff in Bristol and elsewhere in diatom sampling methods, slide preparation and identification as part of the wider training programme for WFD compliance across the UK. The research produced:

i. A CD of the diatom tool to work out the ecological status of a water body.
ii. A video to train agency staff in correct procedures for field sampling.
iii. A report outlining sampling methodology for diatom slide preparation.
iv. Literature to train agency staff and others to identify diatoms.
v. Guidance on measurements of risk of misclassification of the ecological status of rivers.

**Other key collaborators**

- Dr M. Kelly (Bowburn Consultancy) – consultant to EA, SEPA and the Northern Ireland Environment Agency (NIEA). Dr Kelly put together and coordinated the team of experts that collaborated in developing the reference-based diatom tool.
- Dr S. Juggins (Senior Lecturer, School of Geography, Politics and Sociology, Newcastle University) – statistical expert who compiled the databases and developed software to calculate observed and expected indices.
- Dr H. Bennion (Reader, Department of Geography, University College London) – project leader for the lakes component. Dr Bennion collaborated on a Bristol-led MSc by research which included collection of some of the data used for the uncertainty analysis and taxonomic support for building the lake tool.
- Dr H. Hirst (postdoctoral fellow in Yallop's research team at Bristol) – contributed to Bristol-led research as stated above.

**3. References to the research**

**Outputs**

The research carried out by Yallop and her colleagues that led to the delivery of new reference-based, diatom-based tools for assessing UK rivers and lakes has been cited by a number of other countries developing their own assessment tools, including Canada, Norway, Portugal, Spain and Korea.


[1] Kelly, M.G., Juggins, S., Bennion, H., Burgess, A., Yallop, M., Hirst, H., King, L., Jamieson, J., Guthrie, R. and Rippey, B. (2007) *Use of Diatoms for Evaluating Ecological Status in UK Freshwaters,* Environment Agency Science Report SCO30103/SR4 [accessible at https://publications.environment-agency.gov.uk/ms/Ec5loz].

[2] Kelly, M., Juggins, S., Guthrie, R., Pritchard, S., Jamieson, J., Rippey, B., Hirst, H. and Yallop, M. (2008) 'Assessment of ecological status in U.K. rivers using diatoms', *Freshwater Biology,* 53: 403-422. DOI: 10.1111/j.1365-2427.2007.01903.x (70 citations, Google Scholar 18/11/2013).

[3] Yallop, M.L. and Kelly, M.G. (2006) From pattern to process: understanding stream phytobenthic assemblages and implications for determining "ecological status"', *Nova Hedwigia,* 130 (Suppl): 357-372. Can be supplied upon request (11 citations, Google Scholar 18/11/2013).

[4] Yallop, M.L., Hirst, H., Kelly, M., Juggins, S., Jamieson, J. and Guthrie, R. (2009) 'Validation of ecological status concepts in UK rivers using historic diatom samples', *Aquatic Botany,* 90: 289-295. DOI: 10.1016/j.aquabot.2008.11.005 (13 citations, Google Scholar 18/11/2013).

[5] Kelly, M., Bennion, H., Burgess, A., Ellis, J., Juggins, S., Guthrie, R., Jamieson, J., Adriaenssens, V. and Yallop, M. (2009) 'Uncertainty in ecological status assessments of lakes and rivers using diatoms', *Hydrobiologia,* 633: 5-15. DOI: 10.1007/s10750-009-9872-z (33 citations, Google Scholar 18/11/2013).

[6] King, L., Clarke, G., Bennion, H., Kelly, M. and Yallop, M.L. (2006) 'Recommendations for sampling littoral diatoms in lakes for ecological status assessments', *Journal of Applied Phycology,* 18(1):15-25. DOI: 10.1007/s10811-005-9009-3 (33 citations, Google Scholar 18/11/2013).


**Grants:**


[7] Yallop ML. (2003-2007) *Diatoms as Monitors of Ecological Status in Rivers*, Funded by Environment Agency (EA) and Scotland and Northern Ireland Forum for Environmental Research (SNIFFER), £200,000, of which £45,000 was awarded to Bristol.

[8] Yallop ML. (2004-2008) *Development of a phytobenthos classification tool for lakes and lochs of UK,* funded by EA and SNIFFER, £100,000, of which £25,000 was awarded to Bristol.


**4. Details of the impact**

The diatom-based tools for rivers (DARES) and lakes (DALES) were developed by Yallop and her colleagues for use by the regulatory agencies in England, Northern Ireland, Scotland and Wales [a, b], and have subsequently been adopted by Ireland's Environmental Protection Agency [c, p.18]. These statutory agencies have benefited from the development of these tools as previous assessment methods for freshwater bodies did not meet the standards of the EU WFD, which was put into UK law in 2003. "Bristol staff made a major contribution to the development of the models," said the consultant who coordinated the project on behalf of the UK's statutory environment agencies [d], "via data analysis and development of the conceptual model, as well as helping to define the expected state for UK freshwaters. The tools are being used by the EA, SEPA, and NIEA, as well as the Republic of Ireland's Environment Protection Agency and are playing a major role in the regulation of freshwater quality and determining investment patterns for the water industry across the UK and Ireland."

The research leading to the development of the diatom tools was disseminated through agency publications [1] and operational instructions, peer-reviewed literature [2-6] and through participation of agency staff in the research programme. Agency staff were trained to use the tools and by 2009 all lakes and rivers in the UK and Ireland within their remit had been assessed using these diatom-based tools. In England and Wales, 27% of water bodies achieved good ecological status or above; River Basin Management Plans have been drafted for those water bodies that failed to reach good ecological status [e]. The Department for Environment, Food and Rural Affairs (Defra) and the Welsh Assembly Government have estimated that the cost of bringing these water bodies up to good ecological status will be in the region of £194 million (2008 values) [e, pg 2]. These

costs will largely fall on the water industry, financed through increased water charges for consumers [e, p.2]. The benefit, however, is a general improvement to water status, estimated to result in a £200 million (2008 values) benefit to English and Welsh residents over a 43 year period. Benefits include increased resilience of the aquatic environment, improved habitats for commercial fish species and efficiency through better water management, among others [e, p.8]. "The impact of this should not be underestimated," said the Head of Ecology at SEPA [f], "the standards play a very significant role in determining capital infrastructure spend for the water industry."

Subtle differences (e.g., climatic, geological, etc.) within each country mean that the toolkit has to be country-specific. However, other countries have developed similar indices based on the body of work by Yallop and her colleagues. Examples include the Eastern Canadian Diatom Index [g, cites 5] and an index for the western United States [h, cites 2]. "The work also has wider significance in Europe where it was evaluated alongside methods developed by other Member States in order to evolve a 'common view' of ecological status." [d] The results of this intercalibration process are legally binding in the Member States [d]. The diatom-based tool is now being applied to give guidance on UK phosphorus regulatory standards [i, p. 21&29], which will lead to further impact in the future.

A large number of collaborative projects are now underway, working with individual landowners and farmers across the UK with a view to improving water quality in areas failing to meet new WFD requirements on water quality based on the new status assessments. One such collaborative project currently in progress, the Axe and Exe River Improvement Project [j], illustrates the ecosystem benefits that will result from catchment-scale improvements in water quality.

**5. Sources to corroborate the impact**


[a] WFD – UKTAG (2008). *UKTAG rivers assessment methods: Macrophytes and phytobenthos. Phytobenthos – Diatom Assessment for River Ecological Status (DARES).* Edinburgh, Scotland, Pp. 19. ISBN: 978-1-906934-08-8. <http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/River%20phytobenthos.pdf>

[b] WFD-UKTAG (2008). *UKTAG lake assessment methods: Macrophytes and phytobenthos. Phytobenthos – Diatom Assessment of Lake Ecological Quality (DARLEQ).* Edinburgh, Scotland, Pp. 19. ISBN: 978-1-906934-00-2. <http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/Lake%20phytobenthos.pdf>

[c] Environmental Protection Agency (2006). *Ireland: Water Framework Directive Monitoring Program.* Published by the Environmental Protection Agency, Ireland, Wexford, Ireland. Pp. 195. <http://www.epa.ie/pubs/reports/water/other/wfd/EPA_water_WFD_monitoring_programme_main_report.pdf> Evidence that the Irish monitoring project adopted the diatom-based tools.

[d] Partner, Bowburn Consultancy.

[e] Defra and the Welsh Assembly Government (2009). *Impact Assessment of 1st Cycle of River Basin Plans developed to implement the EC Water Framework Directive.* Gives financial estimates for financial benefits of improved water status. <http://archive.defra.gov.uk/environment/quality/water/pdf/national-impact-assessment.pdf>

[f] Head of Ecology, Scottish Environment Protection Agency.

[g] Grenier, M., *et al.* (2010) 'Defining ecological thresholds to determine class boundaries in a bioassessment tool: The case of the Eastern Canadian Diatom Index (IDEC)', *Ecological Indicators,* 10: 980-989. DOI: 10.1016/j.ecolind.2010.03.003 [cites 5].

[h] Stevenson, R.J., *et al*. (2008) 'Development of diatom indicators of ecological conditions for streams of the western US', *Journal of the North American Benthological Society,* 27 (4): 1000-1016. DOI: 10.1899/08-040.1 [cites 2].

[i] WFD-UKTAG (2008) *UK Environmental Standards and Conditions (Phase 1).* Final report (SR1-2006), Pp. 73. Gives evidence that the diatom tool is now being applied to give guidance on UK phosphorus regulatory standards. <http://www.wfduk.org/sites/default/files/Media/Environmental%20standards/Environmental%20standards%20phase%201_Finalv2_010408.pdf>

[j] Hickey, J. (2012) *Axe and Exe River Improvement Project Project Plan,* Pp 20. <http://www.riverexereta.co.uk/files//AERIP%20Project%20Plan.pdf>