Institution: University of Hull		
Unit of Assessment: 14 Geography and Environmental Studies		
Title of case study: A novel, cost-effective tool to transform lake fish monitoring and ecological assessment based on environmental DNA (eDNA)		
Period when the underpinning research was undertaken: September 2014 to present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dr. Bernd Hänfling Dr. Lori Lawson Handley	Reader Senior Lecturer	2007 to present 2007 to present
Period when the claimed impact occurred: January 2015 to present		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact (indicative maximum 100 words)

Research carried out at the University of Hull (UoH) has produced a novel tool for monitoring and assessing the ecological status of lakes based on environmental DNA (eDNA) metabarcoding of fish communities. The tool has been adopted by national agencies within the Department for Environment, Food and Rural Affairs (Defra) i.e. the Environment Agency (EA); the Scottish Environmental Protection Agency (SEPA); Natural Resources Wales (NRW); Natural England (NE); and NatureScot to fulfil monitoring obligations under UK and EU law (i.e. the EU Water Framework Directive 2000/60/EC). **This is the first example of eDNA metabarcoding being adopted for statutory monitoring anywhere in the world.**
This non-invasive method has also been used to generate evidence of species' distributions, informing management decisions relating to Flood Alleviation Schemes, and has been adopted by commercial companies (providing them with significant revenue).

2. Underpinning research (indicative maximum 500 words)

Biodiversity monitoring is essential for assessing human impact on the environment and is a requirement of UK and European legislation such as the Water Framework Directive (WFD). The UK is currently failing to meet national and international legislative requirements for monitoring lake fish populations because existing monitoring methods are costly, time consuming, and can cause harm to organisms and their environment. Environmental DNA (eDNA) is released by organisms into their environments and can be sampled simply by collecting water or soil. eDNA traces in water can therefore reveal the nature and extent of lake fish populations. eDNA is argued to be a 'game-changer' in biodiversity monitoring and is widely regarded as far more cost-effective and less invasive than conventional methods, while having minimum impact on the environment.

Since 2015, our research has pioneered the application of High Throughput Sequencing (HTS) of eDNA (i.e. 'eDNA metabarcoding') to provide data on entire fish communities in freshwater lakes (3.1 – 3.6). This work includes one of the first research papers to provide a practical methodology for monitoring lake fish communities with eDNA (3.1).

Our research during this impact period focussed on:

- Testing, refining and validating eDNA metabarcoding for recovery of information on fish communities across a wide range of lentic environments (3.1 - 3.6).
- Understanding the dynamics of dispersion and degradation of eDNA in lentic waterbodies, which is critical for accurate interpretation of the data (3.3).
- Understanding the temporal and spatial distribution of eDNA in lakes, and providing recommendations for when and where to sample (3.4).
- Demonstrating that data generated from eDNA metabarcoding of lake fish is informative for ecological classification (3.5) and for estimating relative abundance (3.4, 3.5, 3.6).

The key findings of our research are that:

- eDNA metabarcoding consistently outperforms established monitoring methods (gill-netting) for fish species detection (e.g. detecting 12 of the 14 species recorded in Windermere, compared to only 4 by gill-net surveys (3.1, 3.4)).
- eDNA metabarcoding can be considered at least semi-quantitative, as the data correlates significantly with long-term rank abundance data obtained using established methods (3.1, 3.4, 3.5) and with biomass and abundance inferred directly from drained ponds (3.6).
- There is strong spatial structure in eDNA distribution (i.e. where fish species are located in a water body, and in what quantities, informs the development of an efficient sampling strategy to produce the best estimate of the total fish population). This is the case particularly in the summer, which has important implications for choosing when and where to sample, and for estimating relative abundance (using Site Occupancy Modelling approaches (3.1, 3.4)).
- eDNA metabarcoding data provides accurate information on the ecological status of lakes, indicating the data is informative and appropriate for ecological assessments (3.1, 3.5, and output of 3.12).

Combined, these methodological developments and research findings demonstrate that eDNA metabarcoding provides accurate information on the composition of the fish community in lakes, which in turn can provide information on ecological status. Our research has provided the evidence base needed to produce the first eDNA metabarcoding tool for WFD and wider statutory monitoring.

3. References to the research (indicative maximum of six references)

1. **Hänfling, B., Lawson Handley, L.J.,** Read, D.S., Hahn, C., Li, J., Nichols, P., Blackman, R.C., Oliver, A., Winfield, I.J., 2016. Environmental DNA metabarcoding of lake fish communities reflects long-term data from established survey methods. *Molecular Ecology*, 25(13), pp.3101–3119. https://onlinelibrary.wiley.com/doi/abs/10.1111/mec.13660
2. Li, J., **Lawson Handley, L.J.,** Read, D.S., **Hänfling, B,** 2018. The effect of filtration method on the efficiency of environmental DNA capture and quantification via metabarcoding. *Molecular Ecology Resources,* 18(5), pp.1102-1114. http://dx.doi.org/10.1111/1755-0998.12899
3. Li, J., **Lawson Handley, L.J**., Harper, L.R., Brys, R., Watson, H.V., Di Muri, C., Zhang, X., **Hänfling, B,** 2019. Limited dispersion and quick degradation of environmental DNA in fish ponds inferred by metabarcoding, *Environmental DNA*, 5, p.133. https://onlinelibrary.wiley.com/doi/full/10.1002/edn3.24
4. **Lawson Handley, L.J.,** Read, D.S., Winfield, I.J., Kimbell, H.S., Johnson, H., Li, J., Hahn, C., Blackman, R., Wilcox, R., Donnelly, R., Szitenberg, A., **Hänfling, B.,** 2019. Temporal and spatial variation in distribution of fish environmental DNA in England's largest lake, *Environmental DNA*, 1(1), pp.26–39. https://onlinelibrary.wiley.com/doi/full/10.1002/edn3.5
5. Li, J., Hatton-Ellis, T.W., **Lawson Handley, L.J,** Kimbell, H.S., Benucci, M., Peirson, G., **Hänfling, B.,** 2019. Ground-truthing of a fish-based environmental DNA metabarcoding method for assessing the quality of lakes V. Paiva, ed. *Journal of Applied Ecology*, 56(5), pp.1232–1244. https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.13352
6. Di Muri, C. **Lawson Handley, L.J.,** Bean, C.W., Li, J., Peirson, G., Sellers, G.S., Walsh, K., Watson, H.V., Winfield, I.J., **Hänfling, B.,** 2020 Read counts from environmental DNA (eDNA) metabarcoding reflect fish abundance and biomass in drained ponds, *Metabarcoding and Metagenomics*, 4, p. e56959. https://doi.org/10.3897/mbmg.4.56959

Grants awarded (title, funder, PI, CoI (BH = Bernd Hänfling, LLH = Lori Lawson Handley), start date, end date, amount)

7. Evaluation of eDNA based metabarcoding as a monitoring tool for fish in large lakes, Environment Agency, BH, LLH, 01/01/2015 to 30/04/2015, £29,649.00
   Final report https://www.gov.uk/government/publications/a-dna-based-monitoring-method-for-fish-in-lakes

8. Evaluation of eDNA based metabarcoding as a monitoring tool for fish in large lakes – Phase 2, Scottish Environmental Protection Agency, LLH, BH, 01/09/2015 to 29/01/2016, £59,657.00
9. Using eDNA surveys to evaluate the impact of River Thames Scheme Capacity Improvements and Flood Channel Project, Environment Agency, BH, LLH, 01/04/2016 to 31/01/2017, £87,618.00
10. A review of recent advances in genetic methods to identify improvements in CAMERAS partners monitoring activities, Scottish Government, BH, LLH, 15/06/2016 to 14/06/2017, £74,792.00
    Final report https://www.sepa.org.uk/media/335965/cr-2015-09-a-review-of-recent-advances-in-genetic-methods-to-identify-improvements-in-cameras-partners-monitoring-activities.pdf
11. Lake fish classification delivery - Phase 3: Expansion of an eDNA sampling network in Scotland, Scottish Environmental Protection Agency, BH, LLH, 01/11/2017 to 31/10/2018, £39,267.17
12. Development of an eDNA based tool for lake fish monitoring in the UK - collection of data from reference lakes in England, Environment Agency, BH, LLH, 01/11/2018 to 31/03/2019, £57,000.00
    Final results published in http://www.wfduk.org/sites/default/files/January%202020%20UK%20TAG%20Consultation%20Document.pdf pp10-18

4. Details of the impact (indicative maximum 750 words)

The key impact of the research is the development of a completely new, non-invasive way of monitoring lake fish communities and assessing the ecological status of lakes, based on environmental DNA (eDNA) metabarcoding. The method delivers comprehensive data on the distribution of fish, which in turn provides important and accurate information on the ecological status of water bodies, which is a requirement of the Water Framework Directive (WFD) (which protects and improves the water environment, and defines the legal, statutory monitoring requirements for bodies of water).

The eDNA method was **adopted by Defra agencies** for WFD assessment of lakes, following a consultation by the WFD UK Technical Advisory Group (UKTAG) between 6th January and 14th February 2020 (5.1).

This provides the UK with the first fully-operational approach anywhere in the world for lake fish monitoring and WFD assessment using eDNA metabarcoding.

Beneficiaries: The main direct beneficiaries of this work are the Defra agencies that are required to carry out fish community monitoring for regulatory and decision-making purposes, and the private companies (e.g. consultancies such as Nature Metrics) contracted to fulfil this monitoring work.

Benefits, and evidence of benefits, to Defra Agencies:

1. Development of a monitoring strategy based on modern molecular eDNA methods.

   Evidence: Data generated and analysed during a roll-out of the method across 101 UK lakes was included in the UKTAG consultation, which resulted in the adoption of the fish monitoring tool by Defra agencies in 2020 (5.1). In a joint statement by the Environment Agency (EA), Scottish Environment Protection Agency (SEPA) and NatureScot (5.2), the agencies described the research carried out by UoH as: *"having contributed towards achieving a step change"* and having *"already impacted the strategic vision of the agencies and the way lake fish communities are monitored."* (5.2)

2. Providing a method that enables the launch of a lake fish monitoring programme compatible with the WFD, a legal requirement which could not be previously fulfilled.

   Evidence: The method has been *"approved as a WFD monitoring method, following a formal consultation process by the UK WFD Technical Advisory Group*." (5.2)

3. Providing a Standard Operating Procedure (SOP) for lake fish monitoring with eDNA, that can be followed for routine monitoring.

   Evidence: "*Collectively this research has successfully delivered a standard operating procedure covering sampling and lab processes and an assessment procedure that allows the condition of lake fish communities [to be assessed].*" (5.2)

4. Providing evidence in ongoing monitoring programmes.

   Evidence: "*The eDNA based fish monitoring tool developed by UoH is already being deployed in a number of different statutory monitoring programmes carried out by the UK-EAs.*" (5.2). For example, the method was used to provide baseline data on rare and invasive species in 36 lakes of the River Thames floodplain, as part of Environmental Impact Assessments for the proposed London Flood Channel in 2016 and the Oxford Flood Alleviation Scheme in 2018 (5.3). In both cases, lake fish monitoring was required to inform mitigation strategies and develop an environmentally acceptable scheme, to enable assessment of Special Protection Areas and Sites of Special Scientific Interest, and to allow assessment against WFD objectives. Data on species detections (for example the presence of the protected bullhead, *Cottus gobio*) advised decisions on the mitigation of effects of the flood alleviation schemes and was included in the respective impact assessments (5.3).

5. Cost implications and financial impact.

   Evidence: "*The method also provides considerable cost and time savings compared to conventional methods*" (5.2). For Scottish lochs, the estimated cost-saving through the eDNA approach was >£1,000 per lake (even during the proof-of-concept phase), with significant cost reduction expected after further optimisation (as substantially less labour is required, for a shorter period). SEPA will therefore make substantial savings, alongside other regulatory bodies.

Benefits, and evidence of benefits, to the private sector:

The method has been adopted by a commercial company (Nature Metrics) which is offering it as a service to ecological consultancies and other end users. This development has generated commercial and financial benefits. UoH has collaborated closely with the company to facilitate this adoption, producing a standard operating procedure covering sampling and lab processes and assessment of the condition of lake fish communities. The CEO of Nature Metrics states in her letter of support (5.4) that: *"The research provided the foundation for developing a commercial service for fish eDNA metabarcoding, which we have now applied to approximately 2000 client samples from over 20 countries, primarily for purposes of conservation and environmental impact assessment (EIA). This has generated approximately £[redacted] in revenue since 2017".*

Evidence of wider impact:

Throughout this research we have worked closely with Defra agencies and other stakeholders to facilitate the uptake of eDNA-based monitoring more generally. Activities that support the wider impact of our research include:

1. Writing a review of DNA-based methods for the Scottish Government (3.10), which "*contributed significantly to the drive towards using eDNA approaches to Site Condition Monitoring… and environmental quality assessments … and the development of an internal NatureScot Genetics Strategy.*" (5.2)

2. Playing a key role in the development of the UK Earth Observation Framework DNA Working Group (5.5). UoH hosted the 2nd annual meeting in September 2014, and Lawson Handley and Hänfling are members of the steering committee and chair the Fish and Invasive Species Technical Groups (5.5). *"The UoH team have played a critical role in establishing and maintaining this highly active and fast-growing group, which has brought together member organisations from Universities and end user groups."* (5.2)

3. Having an active role in the EU COST action 'DNAqua-Net': a multidisciplinary group of researchers which aims to identify gold-standard genomic tools for aquatic biodiversity monitoring including eDNA approaches, and which works with water managers, politicians and other non-academic stakeholders. Our research was key to an influential perspective paper on the implementation of DNA-based approaches for aquatic biodiversity monitoring (5.6) and led to presentations at numerous national stakeholder meetings across Europe, including to the Working Group of the European Commission's Common Implementation Strategy, ECOSTAT, which is in charge of the implementation of the WFD. The Chair of DNAqua-Net stated that the research team at UoH *"played a key role in influencing major stakeholder groups across Europe in their attitude to the feasibility of implementing DNA based methods for biodiversity monitoring. In some member countries this has already led to the initiation of implementation programmes for monitoring fish communities through the use of environmental DNA*" (5.7).

These three initiatives will sustain the position of UoH at the forefront of the growing development and impact of eDNA-based monitoring, as we help to refine best practice and inform the wider professional, research and academic communities of its applications and further potential.

5. Sources to corroborate the impact (indicative maximum of 10 references)

All available as pdfs on request.

1. UK TAG lake fish assessment standards consultation document (a) and responses (b) publicly available at http://www.wfduk.org/stakeholders/uktag-standards-consultation-january-2020
2. Letter of support signed by Scottish Environmental Protection Agency, Environment Agency, and NatureScot. The letter details the contribution of UoH to developing a strategic vision on DNA-based monitoring and implementing eDNA approaches for lake fish communities within the UK Environment Agencies.
3. Environmental Impact Assessments for the (a) River Thames and (b) Oxford Flood Alleviation Schemes.
4. Letter of support from the CEO of Nature Metrics (https://www.naturemetrics.co.uk/) describing their commercial adoption of the method.
5. Evidence of membership of the Earth Observation Framework DNA Working Group steering committee and chairing of the fish and invasive species technical groups http://www.ukeof.org.uk/our-work/ukdna, together with programme for the annual conference, held at UoH 18th – 19th September 2014, which focussed on identifying end user needs for DNA based monitoring (http://www.ukeof.org.uk/documents/uk-dna-wg-meeting-files/2014-dna-wg-agenda-hull).
6. Hering. D., Borja, A., Jones, J.I, Pont, D., Boets, P., Bouchez, A., Bruce, K., Drakare, S., **Hänfling, B.,** Kahlert, M., Leese, F., Meissner, K., Mergen, P., Reyjol, Y., Segurado, P., Vogler, A., Kelly, M. Implementation options for DNA-based identification into ecological status assessment under the European Water Framework Directive. *Water Res.* 2018;138: 192–205. https://www.sciencedirect.com/science/article/abs/pii/S0043135418301830?via%3Dihub
7. Letter of support from Chair of the EU COST Action DNAqua-Net CA15219 (https://dnaqua.net), stating how expertise from UoH has played a key role in influencing major stakeholder groups across Europe in terms of implementing DNA-based methods for biodiversity monitoring.