Institution: 10007857 (Bangor University)

Unit of Assessment: 07 Earth Systems and Environmental Sciences

Title of case study:
International conservation and restoration of peatland and improved drinking water quality through peatland carbon sequestration research

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

Our research has impacted on UK and international policy on peatland/wetland conservation and restoration for climate change mitigation and water purification, by showing how peatlands function as a major global carbon sink and regulator of climate and water quality. Additionally, our discovery that peatland carbon release, from local to global scales, is controlled by a single enzyme system has provided a tool to prevent carbon loss from degraded peat. Our new methods have been implemented in peatland restoration projects by UK agencies and NGOs, benefiting carbon storage, biodiversity and landscapes; raising public awareness and improving UK water industry management leading to better water quality.

2. Underpinning research (indicative maximum 500 words)

Research led by Professor Chris Freeman (at Bangor 1986-present) since 1994 made major new discoveries about the capacity and processes of carbon capture in peatlands/wetlands, improving understanding of their function in carbon storage and identifying key mechanisms to prevent carbon loss by microbial enzyme activity under changing conditions (global warming, drought).

Between 1994 and 1997 (e.g. Freeman *et al.* 1995), the Bangor team, including Freeman, Dr S.E. Jones (Research Officer May 1990 - October 2000) and Dr M.A. Lock (Reader at Bangor since October 1988, Honorary Reader since September 2007), identified experimental procedures that can overcome the interferences on microbial activity that are responsible for the lack of degradation of organic matter in peat. This breakthrough opened up the entire field of peatland enzymology, revolutionising our understanding of the regulation of peatland carbon cycling. Their subsequent research has shown that phenolic compounds suppress soil microbial metabolism and impair decomposition, fostering sequestration of a vast global peatland carbon store (455 Gt), whilst occupying just 3% of the Earth's land area (Freeman, P.I. with Royal Society, NERC and Leverhulme Trust funding). Freeman and Dr N. Fenner (Research Officer since 2003, Lecturer since January 2011) found that exports of dissolved organic carbon (DOC) from peatland have approximately doubled since 1988, and are predicted to increase further with global warming (Freeman *et al*. 2001a). This trend is being accelerated by increased primary production, including the impact of elevated CO_2 (Freeman *et al.* 2004). They subsequently discovered synergy between elevated-CO_2 and warming effects on the rate of peatland C cycling, now interpretable through their finding that *Sphagnum* retains C for orders of magnitude longer than vascular plant species. Since elevated CO_2 greatly favours vascular plants over *Sphagnum*, they predict a further acceleration of C losses (Fenner *et al.* 2007).

Freeman discovered the mechanism controlling peatland C losses through decomposition of organic matter: phenol oxidase is one of the few enzymes capable of eliminating phenolic inhibitors (Freeman *et al.* 2001b). The team then made the first molecular study of enzymes in peatlands (Fenner *et al.* 2005), discovering that drought increased the diversity of microbes able to eliminate phenolic inhibitors, further undermining the stability of peatland C stores. They showed that this effect is compounded by increased N deposition, promoting both DOC- and CO_2-mobilisation (Bragrazza *et al.* 2006). The importance of this research has been recognised by prestigious funding from the Royal Society and Wolfson Foundation to establish a carbon capture laboratory (2010). The £398k grant was the largest that the committee has awarded to date.

Recently, the research has extended to tropical peatlands, one of the planet's largest terrestrial C stores. Findings have demonstrated that since 1990, peat-swamp conversion to palm oil

plantations in SE Asia is releasing ancient carbon stores previously retained by the enzymic latch, and increasing fluvial C flux by over half of the total fluvial flux from European peatlands, which offsets C-sequestration benefits associated with biofuels (Moore *et al.* 2013).

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

Bangor authors are in **bold**. Citation counts obtained through Google Scholar (October 2013).

Bragazza, L., **Freeman, C., Jones, T.**, Rydin, H., Limpens, J., **Fenner, N., Ellis, T.,** Gerdola, R., Hajek, M., Hajek, T., Lacumin, P., Kutnark, L., Tahvanainen, T. and **Toberman, H.** 2006. Atmospheric nitrogen deposition promotes carbon loss from peat bogs. *Proceedings of the National Academy of Sciences of the USA* **103**: 19386-19389. DOI: 10.1073/pnas.0606629104. In peer-reviewed journal, 153 citations, submitted to RAE 2008.

Fenner N., Freeman C. and Reynolds, B. 2005. Hydrological effects on the diversity of phenolic degrading bacteria in a peatland: implications for carbon cycling. *Soil Biology & Biochemistry* **37**: 1277-1287. DOI: 10.1016/j.soilbio.2004.11.024. In peer-reviewed journal, 57 citations.

Fenner, N., Ostle, N.J., McNamara, N., Sparks, T., Harmens, H., Reynolds, B. and **Freeman, C**. 2007. Elevated CO_2 effects on peatland plant community carbon dynamics and DOC production. *Ecosystems* **10**: 635-647. DOI: 10.1007/s10021-007-9051-x. In peer-reviewed journal, 39 citations.

Freeman, C., Evans, C.D., Monteith, D.T., Reynolds, B. and **Fenner, N.** 2001a. Export of organic carbon from peat soils, *Nature* **412**: 785-785. DOI: 10.1038/35090628. In peer-reviewed journal, 532 citations, submitted to RAE 2008.

Freeman, C., Fenner, N., Ostle, N.J., **Kang, H., Dowrick, D.J.,** Reynolds, B., **Lock, M.A.,** Sleep, D., Hughes, S. and Hudson, J. 2004. Export of dissolved organic carbon from peatlands under elevated carbon dioxide levels. *Nature* **430**: 195-198. DOI: 10.1038/nature02707. In peer-reviewed journal, 342 citations, submitted to RAE 2008.

Freeman, C., **Liska, G., Ostle, N.J., Jones, S.E.** and **Lock, M.A**. 1995. The use of fluorogenic substrates for measuring enzyme activity in peatlands. *Plant & Soil* **175**: 147-152. DOI: 10.1007/BF02413020. In peer-reviewed journal, 101 citations.

Freeman, C., Ostle, N. and **Kang, H.** 2001b. An enzymic 'latch' on a global carbon store - A shortage of oxygen locks up carbon in peatlands by restraining a single enzyme. *Nature* **409**: 149-149. DOI: 10.1038/35051650. In peer-reviewed journal, 413 citations, submitted to RAE 2008.

Moore, S., Evans, C.D., Page, S.E., Garnett, M.H., **Jones, T.G.**, **Freeman, C.** Hooijer, A., Wiltshire, A.J., Limin, S.H. and Gauci, V. 2013. Deep instability of deforested tropical peatlands revealed by fluvial organic carbon fluxes. *Nature* **493**: 660-663. DOI: 10.1038/nature11818. In peer-reviewed journal, submitted to REF 2014.

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

The research of Freeman and colleagues has strongly influenced ongoing and major developments in wetlands policy and peatland management and restoration by international organisations, UK government, industry and NGOs.

Impact on water Industry

Freeman's discovery that peatland degradation is the cause of increasing DOC levels in water provided the explanation to water companies for rising costs of water treatment. It formed the evidence base for strategic planning and management decisions to reduce water DOC levels, through improved land management of peatland catchments, and restoration activities such as ditch blocking. Freeman's findings have made it possible, for the first time, to address these water quality problems at the source; the upland catchments themselves, rather than focusing on costly end-of-pipe technological water treatment solutions. This has directly led to new jobs through the creation of specialised catchment management teams and new water treatment measures by the water industry, including water companies Welsh Water and United Utilities – improving drinking

water quality for at least 5 million households in England and Wales [2]. According to Welsh Water's Operations Director: "*through implementation of management adjustments to rising trends in DOC, every UK customer receiving water from upland catchments, has benefitted from improved water quality through this research"* [2]. The research findings have been the justification for millions of pounds of funding secured by the water companies, and central to further investments driven by their increasing recognition of ecosystem services and the importance of peat carbon storage [1].

Impact on international and national wetlands policy and restoration measures

As a result of the impact of his 2001 and 2004 Nature papers, Freeman was invited onto several international committees on wetland restoration and, unusually, to act as an international advisor to the US National Science Foundation on the allocation of $36M of funding in the field of climate change and carbon cycling. Freeman's recent work, including his 2013 Nature paper, has already had a significant impact on the international debate about the net benefit of using palm oil as a biofuel for climate change mitigation and the role of peatlands in post-2012 climate change legislation in the Kyoto Protocol [10] and is referenced in the 2013 Supplement to the 2006 IPCC Guidelines. Freeman's research was key in underpinning future UK scenario forecasts on water quality and in making the case for the importance of peatland restoration in combatting climate change [e.g. 6-8]. Engagement with UK policy makers has continued to be integral to Freeman's research. E.g., with team member Dr Joanne Clark, Freeman edited a special Issue of *Climate Research* ("Climate Change and the British Uplands", Vol. 45, December 2010) targeted at informing policy makers about safeguarding wetland ecosystem services (water purification, C storage and mitigating climate change) [7]. The Welsh Assembly Government has used the research repeatedly in identifying further research needs and developing policy on natural resource planning since 2008, such as the agri-environment scheme, Glastir, and the Welsh Soils Action Plan [3].

Impact on peatland conservation and restoration measures

Freeman's research has provided a scientific evidence base for land conservation managers, trusts and NGOs, often in close collaboration with water companies, for their decisions to focus resources and efforts towards peatland conservation and restoration [1,2]. In particular, the resulting knowledge of the enzymic "latch" had a major global impact – the role of phenol oxidase inhibition for C sequestration in peat has "*helped conservation bodies to demonstrate the need for early restoration work to bring peatland sites into the best possible condition*" [4]. It has evidenced one of the most feasible means to reduce degradation and C loss from C-rich wetlands through ditch blocking and floatable organic structures that capture inorganic pollutants by making use of the enzymic latch system (patent pending). This has justified significant funding for peatland restoration in intensively managed catchments [1,4,9] and by the peat moss industry internationally [5]. For example, the Llyn Fens LIFE+ project awarded to the Countryside Council for Wales (2009-2014) that restores 751 ha of important European wetland habitat, makes extensive use of constructed wetland technology developed by Freeman to help intercept and retain nutrient inputs to semi-natural wetland sites, and draws on Freeman's expertise by incorporating practical recommendations on restoration techniques from his research [4,9]. Freeman's research led directly to acknowledgment of the important function of peatlands in water purification, C storage and combatting climate change, leading directly to improved conservation, with consequences for increased biodiversity value and ecosystem services, of these globally important habitats [4]. As an example of the international impact of this work: the Canadian Sphagnum Peat Moss Association, dedicated to preservation and responsible harvesting of Canadian peatlands, has in March 2013 commenced the world's first large-scale field trials of the enzymic latch approach, investing a total of $175,000 in the approach to improve peatland re-vegetation and increase C-sequestration [5].

Impact on public awareness

The findings of Freeman's research have been disseminated widely in the public arena. He has a consistent record of high level engagement with stakeholders and peer recognition for his research achievements since 1997 which has, cumulatively, led to the major impact of his research since 2008 on stakeholder and public awareness. Freeman was awarded the Lindeman Award of the American Society of Limnology and Oceanography (1997), invited by Lord May, Past President of

the Royal Society, to discuss research with HRH Prince of Wales (2001), awarded the Royal Society Brian Mercer Feasibility Award (2004), invited to the Queen's Reception for Scientists (2005) and awarded the Royal Society Mullard Medal (2007) in recognition of his significant contributions to knowledge on climate change and the importance of peatlands and to the significance of this work for national prosperity. In 2013, Freeman was elected a Fellow of the Society of Wetland Scientists, based in the USA: something that had only happened 23 times since 1980 within an organisation of 3500 members. His research has been featured before and since 2008 in articles by the BBC and Huffington Post and on television. Continued viewings of his footage on YouTube [10] (over 7000 views since 2008) reflect an ever-increasing impact on public awareness of the importance of peatland conservation. According to the principal Peatland Ecologist of the Countryside Council for Wales (now Natural Resources Wales), the fact that "*someone of Freeman's reputation and status actually uses publically owned conservation sites as research facilities helps make the case for the retention of these very important but quite expensive to run assets*" [4]. Therefore, in addition to the research itself, the prestigious reputation Freeman has gained, is in itself contributing to the conservation of these important areas [4].

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

Statements available on request that confirm impacts on water industry and policy makers:

1. Formal Statement by Penny Anderson Associates Ltd, Lead Consultancy for Water Industry bodies
2. Formal Statement by Operations Director of Dŵr Cymru Welsh Water
3. Formal Statement by the Strategic Monitoring and Soil Policy Department of Welsh Government
4. Formal Statement by Senior Peatland Ecologist of Natural Resources Wales
5. Formal Statement by the President of Canadian Sphagnum Peat Moss

Examples of Policy Documents and NGO reports referencing the research:

Copies of these documents with the sections referencing Bangor research highlighted are available on request

6. Worrall, F., Chapman, P., Holden, J., Evans, C., Artz, R., *et al.*, 2011. A review of current evidence on carbon fluxes and greenhouse gas emissions from UK peatland. JNCC Report, No. 442. Available at: http://jncc.defra.gov.uk/pdf/jncc442_webFinal.pdf
7. Bain, C.G., Bonn, A., Stoneman, R., Chapman, S., Coupar, A. *et al.,* 2011. IUCN UK Commission of Inquiry on Peatlands. IUCN UK Peatland Programme, Edinburgh. Available at: www.iucn-uk-peatlandprogramme.org
8. Scientific Reviews for the IUCN UK Peatland Programme's Commission of Inquiry on Peatlands (*chapters on Peatland Hydrology, - Restoration and - Climate Change*). Available at: http://www.iucn-uk-peatlandprogramme.org/resources/178
9. Countryside Council for Wales, 2007. Restoring alkaline and calcareous fens within the Corsydd Môn a Llyn (Anglesey & Lleyn Fens) SACs in Wales. Application to the EU LIFE+ Fund, CCW HQ. Copy available on request.

10. **Selected examples of media coverage of Freeman's work** can be found here:
    - Huffington Post Coverage of the recent Moore et al. 2013 paper (Jan 2013): http://www.huffingtonpost.com/2013/01/30/palm-oil-biofuels_n_2583106.html#slide=1212104
    - ScienceBlog on the relevance of the research to amendments of the Kyoto Protocol: http://scienceblog.com/46729/scientists-find-gold-in-british-bogs/
    - YouTube footage featuring Freeman and his research is available through the following channel: http://www.youtube.com/user/cf00?feature=c4-feed-u