Institution:
UNIVERSITY OF LIVERPOOL

Unit of Assessment:
UOA5 – Biological Sciences

Title of case study:
Protection and Improvement of Aquatic Ecosystems threatened by Global Change

1. Summary of the impact

A large body of University of Liverpool (UoL) research on climate and nutrient impacts on aquatic ecosystems has had two notable impacts. 1) Adoption by the Broads Authority in 2008 of new water salinity targets that were proposed by UoL to manage nutrients levels, improve badly affected water quality, and hence raise conservation and amenity value. Ongoing improvements affect many of the 7 million visitors per year, who contribute c£400m to the local economy. 2) Incorporation into public documents by governmental and environmental bodies in the UK and US that warn water users of the UoL finding of the likely increase in the threat posed by an invasive water weed under climate warming. The weed constitutes a serious danger to amenity, tourism and conservation on several continents.

2. Underpinning research

Two of the greatest and increasing environmental threats worldwide are climate warming and the increased loading of nutrients into rivers, lakes and the sea. Between them they cause large-scale fish kills, reduce biodiversity by destroying diverse habitats, ruin water quality, and deplete the supply of products and services that support local economies.

The UoL group, one of the leading research groups in this area, discovered specific impacts of warming on lake water quality, including nutrient levels, and on the spread of an African invasive weed species [2-4]. In later experiments [1] the group discovered an effective way of reducing excess nutrients and environmental deterioration in freshwaters subject to saltwater seepage, and proposed ecologically-based targets for reducing salinity and harmful impacts of excess nutrients.

The research used the largest experimental facility in Europe for investigating the combined impacts of climate change and nutrient enrichment (eutrophication) on freshwaters, which is based at the UoL. This comprised 48 outdoor ponds with the capacity to precisely simulate particular warming scenarios and to alter other environmental stressors including nutrient loading and salinity.

In a NERC-funded study the group simulated the impacts of 21st century warming predicted by the Intergovernmental Panel on Climate Change (IPCC), by warming replicated complete ecosystems from September 1998 to September 2000. These different heating treatments were combined with different amounts of nutrient and fish addition. Key findings from the study, which was cited by the Intergovernmental Panel on Climate Change (2007), included significant detrimental impacts of warming on water quality through increased phosphorus concentrations, decreased oxygen saturation and increased frequency of severe de-oxygenation. It also found that while the communities were mostly resilient to warming, a notable impact was the increase in abundance of an exotic plant, which, while originating in Africa, has the known potential to become problematic as a weed in temperate waters.

The research was entirely carried out at UoL in the period 1998-2007. Dr David Atkinson was Principal Investigator, and co-investigators were Prof B Moss (retired 2008), and Drs JW Eaton (retired 2005), and IF Harvey (retired 2011). D Mckee was employed as postdoctoral researcher (left 2000).

The same experimental system was later used in another UoL NERC-funded study from 2002 to 2005 to investigate the ecosystem impacts of fish and increased salinity – which were predicted to alter nutrient dynamics and environmental quality – by simulating a range of possible conditions in Hickling Broad, Norfolk. An increased proportion of saline water was found to reduce zooplankton grazing and increase phosphorus release from sediment. Both led to increased phytoplankton abundance, reduced abundance of plants, and associated environmental deterioration. During this

experiment, T Barker was employed as postdoctoral researcher (left 2013), B Moss retired in 2008; L Bagnell was an undergraduate student (left 2007) and the others remain as research technicians.

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

1. **Barker T**, **Hatton K**, **O'Connor M**, **Connor L**, **Bagnell** L and **Moss B** (2008). Control of ecosystem state in a shallow, brackish lake: implications for the conservation of stonewort communities. Aquatic Conservation 18: 221-240. DOI: 10.1002/aqc.819 Impact Factor: 1.917

2. **McKee D**, **Hatton K**, **Eaton JW**, **Atkinson D**, **Atherton A**, **Harvey I** and **Moss B**. (2002). Effects of simulated climate warming on macrophytes in freshwater microcosm communities. Aquatic Botany 74: 71–83. DOI: 10.1016/S0304-3770(02)00048-7 Impact Factor: 1.593

3. **McKee D**, **Atkinson D**, **Collings SE**, **Eaton JW**, **Gill AB**, **Harvey I**, **Hatton K**, **Heyes T**, **Wilson D** and **Moss B**. (2003). Response of freshwater microcosm communities to nutrients, fish, and elevated temperature during winter and summer. Limnology and. Oceanography 48:707-722. URL: http://www.jstor.org/stable/3096573 Impact Factor: 3.405

4. **Moss B**, **McKee D**, **Atkinson D**, **Collings SE**, **Eaton JW**, **Gill AB**, **Harvey I**, **Hatton K**, **Heyes T** and **Wilson D**. (2003). How important is climate? Effects of warming, nutrient addition and fish on phytoplankton in shallow lake microcosms. Journal of Applied Ecology 40: 782-792. DOI: 10.1046/j.1365-2664.2003.00839.x Impact Factor: 4.740

Key research grants

1998-2000 **NERC** GR3/11438. Environmental warming and the functioning of freshwater ecosystems. £258K. PI. D. Atkinson.

2002- 2005 **NERC** NER/A/S/2002/00759. Switching mechanisms, biodiversity and ecosystem stability in complex shallow lake communities. £179K. PI. B. Moss.

4. Details of the impact

The experiment on environmental warming and nutrient loading was initially disseminated via high-impact scientific publications and presentations to international and national conferences. The causes for concern that our findings demonstrated - the spread of exotic invasive species and reduced water quality - were then identified by the IPCC [5], and supported by specific reference to two UoL publications [3,4]. Throughout the REF reporting period, IPCC (2007) has continued to be the most authoritative and widely used source underpinning policy statements on responses to changes in the Earth's climate and the impacts of these, and will only be superseded in 2014 by the new IPCC report on impacts, adaptation and vulnerability. In 2008 onwards, the threat of increased spread of the invasive weed in a warmer climate has been picked up by governmental departments in the USA and Northern Ireland [7,8].

More specifically, and during the reporting period, the group's published findings on risks of spread of the exotic curly waterweed, *Lagarosiphon major,* from Africa [2] have been incorporated into online documents by National Museums Northern Ireland [7] and Wisconsin Department of Natural Resources [8], both governmental departments that have taken the initiative to provide advice on protection from invasive species for managers of natural resources and for the general public. Both in Northern Ireland, where this plant has invaded, and Wisconsin, where it has not yet arrived, climates are far from African, but the UoL research work warns of the threat of rapid spread even in temperate latitudes under predicted climate warming. Both specialists and members of the general public are therefore warned of its potential to spread in a warmer climate and are provided with information to help identify and rapidly control this invasive species, benefitting the public and the

nature conservation value of water bodies in these regions. The impact of alerting the public and managers of invasive spread is evidenced by the fact that it is listed on global and several national lists of invasive species of concern, and that the International Union for the Conservation of Nature's global invasive database says: "it can block the intakes of hydro-electric systems. Dense growth ... can block light penetration into waterways, eliminating growth of native water plants and affecting associated populations of aquatic invertebrates. *Lagarosiphon major* can also restrict the passage of boats and limit recreational activities like swimming and angling. Storms can tear weed mats loose and deposit large masses of rotting vegetation on beaches, spoiling their amenity value." (http://www.issg.org/database/species/search.asp?sts=sss&st=sss&fr=1&x=18&y=6&sn=lagarosiphon+major&rn=&hci=-1&ei=-1&lang=EN)

The UoL work on how to improve environmental quality in freshwaters subject to saltwater seepage was performed specifically to help rectify a serious environmental problem faced by the Broads Authority, which is responsible for managing Britain's largest protected wetland and third largest inland waterway. Over 7 million people a year visit the Broads for boating, angling, and nature tourism, spending upwards of £400m in support of the local economy. Many of these are the beneficiaries of the ongoing environmental improvement instigated by the research, as its recommendations have been implemented in the management of the Upper Thurne [6] which occupies about a fifth of the 300 km^2 catchment of the Broads, and is particularly popular because it contains some of the richest biodiversity, angling and boating opportunities.

Prior to the UoL research, there had been deterioration of the ecosystems and instability of the water plant populations, risking sudden shifts to a system with poor water quality, and much reduced biodiversity including a heavily depleted plant community and fewer fish and rare and specialist wildlife. The proposed salinity targets generated by the group's research led to the management activities which continue today (that is, 2008-present), as Broads Authority managers corroborate [9]. Specifically, the Authority responded to the recommendations by instigating four projects throughout the Upper Thurne to invest in and manage pumps, realign dykes, assess water management regimes in catchments, and install a water control and ochre settling reedbed [9]. One of these, the Brograve drainage project, affects the whole of the Upper Thurne, ~ 60 km^2. Clear benefits that have already been observed include greatly reduced salinity levels in Brograve and Eastfield Levels, Horsey Mere, and Hickling Broad (600 ha) [9]. Hickling Broad is the largest expanse of open water in the Broads and has been formally designated for its conservation importance nationally (Site of Special Scientific Interest, National Nature Reserve) and internationally (Ramsar wetland site of international importance; European Union Special Area of Conservation and Special Protection Area). Importantly, this new management has alleviated the previously serious sediment deposition problem in the nearly 1.5 mile long Waxham Cut, and removed the ochreous discolouration of Horsey Mere [9]. The work has prompted further trials of the ecological impact of UoL management recommendations and feature in the strategy for the Upper Thurne and the Broads [9].

In their implementation of UoL recommendations, the Broads Authority work with local farmers and landowners; five are on the steering committee of the Brograve drainage project. Other partners are Natural England, the Environment Agency, Water Management Alliance, Norfolk Wildlife Trust, and parish councils.

These actions to reduce salinity, and hence improve water quality, and the growth and stability of the water plant community, help the managers to determine a cutting regime that will reconcile the demands of the boating community and nature conservation. Beneficiaries are therefore varied, as clean diverse plant dominated communities favour fish populations for anglers, benefit the specialist "flagship" birds such as bitterns and cranes which attract wildlife tourism, and enable coexistence of boating and conservation interests.

The implementation of the UoL recommendations is attracting international interest from drainage authorities, such as that for the Po Delta in Italy, which is charged with ameliorating similar environmental problems in Italy [9].

5. Sources to corroborate the impact

Each source listed below provides evidence for the corresponding numbered claim made in section 4 (details of the impact).

6. Fischlin A et al. (2007). Ecosystems, their properties, goods, and services. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272.

   The citation in the IPCC Report can be checked at www.ipcc.ch

7. Holman IP and White SM. (2008). *Synthesis of the Upper Thurne Research and Recommendations for Management. Report to the Broads Authority.* http://www.broads-authority.gov.uk/broads/live/authority/publications/conservation-publications/Thurne_Research.pdf

8. National Museums Northern Ireland (2008). Invasive Alien Species in Northern Ireland. *Lagarosiphon major*, Curly waterweed. http://www.habitas.org.uk/invasive/species.asp?item=2117

9. Wisconsin Department of Natural Resources (2010) Aquatic Invasive Species Literature Review – *Lagarosiphon major*. http://dnr.wi.gov/topic/Invasives/documents/classification/Lagarosiphon%20major.pdf

10. Letter: Broads Authority Senior Ecologist describing how our published research and recommendations have led to greatly improving targeted management and environmental quality of the Broads.