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Modelling the effects of climate and land-use change on the hydrochemistry and ecology of the River Wye (Wales)

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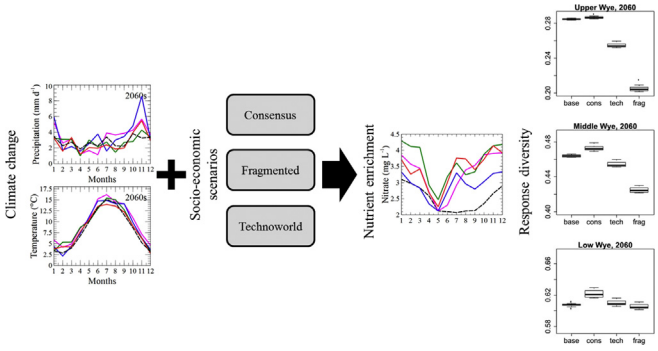
HIGHLIGHTS

- Socio-economic scenarios used to assess future changes in river nutrients and biota.
- Climate change expected to cause nutrient enrichment.
- Longitudinal position along the river mediates ecological response.
- Land-use change plays critical role in mitigation of climate change.

GRAPHICAL ABSTRACT



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ABSTRACT

Interactions between climate change and land use change might have substantial effects on aquatic ecosystems, but are still poorly understood. Using the Welsh River Wye as a case study, we linked models of water quality (Integrated Catchment - INCA) and climate (GFDL - Geophysical Fluid Dynamics Laboratory and IPSL - Institut Pierre Simon Laplace) under greenhouse gas scenarios (RCP4.5 and RCP8.5) to drive a bespoke ecosystem model that simulated the responses of aquatic organisms. The potential effects of economic and social development were also investigated using scenarios from the EU MARS project (Managing Aquatic Ecosystems and Water Resources under Multiple Stress). Longitudinal position along the river mediated response to increasing anthropogenic pressures. Upland locations appeared particularly sensitive to nutrient enrichment or potential re-acidification compared to lowland environments which are already eutrophic. These results can guide attempts to mitigate future impacts and reiterate the need for sensitive land management in upland, temperate environments which are likely to become increasingly important to water supply and biodiversity conservation as the effects of climate change intensify.

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1. Introduction

Reports from the Paris Agreement and the Intergovernmental Panel on Climate Change (IPCC) (Pachauri et al., 2014) have made clear the global significance of climate change driven by anthropogenic sources of carbon dioxide. The positive and negative impacts of climate change across the globe are still being considered and debated, but the potential changes in precipitation, temperature and sea level rise over the next century are likely to have important impacts on hydrology, water quality and ecology (Whitehead et al., 2009). The IPCC report considers the impacts of socioeconomic change superimposed on climate change, showing how socio-economic pathways (SSPs) will interact with climate change to generate a combined impact on people and livelihoods. This provides an integrated framework for addressing issues of change for national, regional and local governments and organizations to consider.

Previous studies have highlighted the importance of cross-sectorial approaches to assess the impacts of climate change on river water quality and ecosystems. For example, Palmer et al. (2009) pointed out the importance of collaborations among multiple partners and wise land use planning to minimize additional development in watersheds with valued rivers, stating that special attention should be given to diversifying and replicating habitats of special importance. Meyer et al. (1999) reviewed models that could be used to explore potential effects of climate change on freshwater ecosystems and discussed potential ecological risks, benefits, and costs of climate change. However, very few examples of integrate modelling approaches for the assessment of climate and land use change impacts on aquatic ecosystems and water quality exist in the literature.

The IPCC report and the EU Water Framework Directive (Chave, 2001; EU, 2000) have provided a backdrop to the MARS project (Managing Aquatic Ecosystems and Water Resources under Multiple Stress) funded by the European Union under the 7th Framework Programme (Hering et al., 2015). In any such study there is a need to understand the effects of multiple stressors on surface waters and groundwaters, their biota, and the ecosystem services they provide to people. River ecosystems are very likely to be affected by land-use or climate changes (Strayer and Dudgeon, 2010). Several studies have observed a reduction in diversity or abundance of river organisms in response to land-use (e.g., Gutiérrez-Cánovas et al., 2013), climate change (e.g., Durance and Ormerod, 2007) or anthropogenic disturbances (Ruhí et al., 2015). The reduction in river biodiversity is likely to reduce the capacity of these ecosystems to provide essential goods and services (Hooper et al., 2005) such as clean water.

As part of the MARS project, upland Wales has been investigated as a Northern Region that has been subject to much environmental change over the past 50 years (Durance and Ormerod, 2007; Whitehead et al., 1998a, 2009). Many of the upland headwaters in mid and southern Wales drain into large river systems and one of those is the River Wye (Fig. 1). In this study we evaluate the River Wye in terms of its hydrology, water quality and ecology and how these might change under a changing climate and changing socio-economic pressures. We utilise the INCA suite of models (Wade et al., 2002; Whitehead et al., 1998a) to quantify the change and use the model to simulate new future approaches to manage the environment.

2. The WYE catchment

The River Wye catchment is located in the Western Regions of the UK, in South and Mid- Wales, as shown in Fig. 1. It flows from Mid-Wales towards South-East Wales, reaching the River Severn estuary and the Bristol Channel at the town of Chepstow. Its catchment area is 4131 km^2. The catchment is included into the following coordinates (degrees latitude/longitude datum WGS84): N: 52.5, W: −3.8, S: 51.6, E: −2.4.The Rivers Lugg and the Monnow are its main tributaries, flowing into the main River Wye reach downstream of Hereford (Jarvie et al., 2005). The main land use is agriculture with livestock farming predominating in the north and west and more intensive arable farming in the south and east of the catchment. There is some industry based around the major towns (e.g. Monmouth and Chepstow). The upland areas of the catchment are generally used for rough grazing, while lowland areas support mixed and dairy-farming and horticulture (Oborne et al., 1980). The water quality of the River Wye is characterised by patterns of high winter concentrations of nitrate and

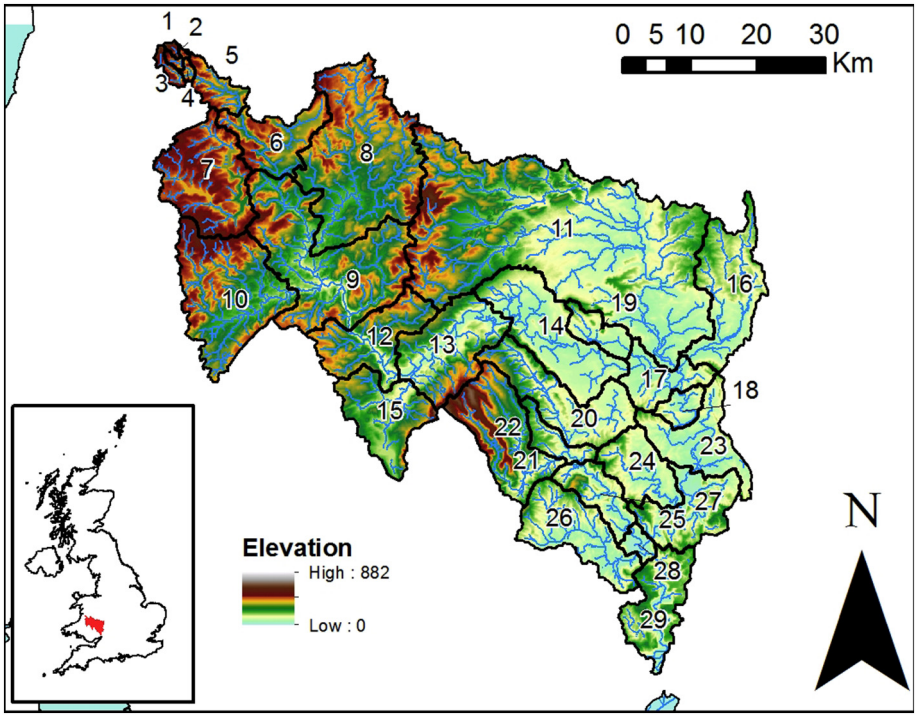

Fig. 1. The River Wye catchment and the INCA model sub-catchments.