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The importance of scale in the development of ecosystem service indicators?

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ABSTRACT

Understanding the interactions between ecosystems and their underlying environmental constraints, the services which they provide, and the people benefiting from those services, are essential for the effective management and sustainability of socio-ecosystems (ecosystems which support and are impacted upon by humans). Ecosystem service (ES) indicators attempt to provide a means of measuring service provision, but the scale at which they are developed is likely to impact on how they can be used to influence the effective management of socio-ecosystems. This paper compares science and practice in the development of service measures at contrasting scales in: (a) an active research project, focused on local catchment management to improve water quality at Loweswater in the English Lake District, and (b) a science-based study developing national scale indicators of water quality using the Countryside Survey dataset.

The paper explores different approaches taken towards the production of ecological measures, which inform on either single or multiple ES delivery across the land/water interface, dependent on scale. It considers how scale impacts on the process of gathering data and on the types of data which can contribute to ES indicators. It further reflects on how service indicators representing different scales of study may be used and by whom. Local scales, in this case the catchment scale, provide a valuable socio-ecological unit for exploring ES delivery, but the extent to which ecosystem service indicators may be used by local actors is uncertain. Larger scale studies may be confined to single services by virtue of data availability but can provide useful policy tools for targeting action. The paper concludes that 'scale' is an important consideration when developing ES indicators. It also concludes that questions around the utility of such indicators should consider the relevance of scale and how it relates to governance.

1. Introduction

All ecosystems, both managed and unmanaged have an important role in supporting human well-being (Millenium Ecosystem Assessment, 2005) through the provision of multiple ecosystem services (ES) including, for example: food production, clean air and water and cultural services, such as recreation. These services are themselves underpinned by natural capital: soils, waters, habitats and species. In managed ecosystems, an understanding of the actual and potential impacts that land managers and occupiers have on their environment is vital to achieving sustainable use of natural capital and the ES that flow from it (Daily and Matson, 2008; Swinton et al., 2007). Rather than tackling complexity by reducing the scope of our science, the challenge for scientists is to open out our science and address the inherent complexities of socio-ecosystems; ecosystems which support and are impacted upon by humans (Carpenter et al., 2009; de Lange et al., 2010). Science seeking to support sustainable resource management needs to be able to produce indicators that reflect such complexity.

Scientists have employed a range of approaches to try to take on board the inherent complexity of socioecological systems when developing indicators (McVittie et al., 2015). Such approaches attempt to measure both indirect and direct human impact on natural capital through for example, land management, or diffuse pollution impacts on waterbodies. Through measuring such impacts the potential for improving management to enhance the production of ES is increased. A number of key factors are likely to be important for measuring and managing human–ecosystem

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interactions. This paper considers the relevance of 'scale', and factors associated with it, for the development of ES indicators.

1.1. Scale

Identifying scales which are relevant to both social and natural systems is difficult, especially in a globalised world where the goods produced by one part of the world may be consumed by humans from another, e.g. tea produced in India and drunk in the UK, or lamb produced in northern England and consumed in the south-east of England. Inevitably the larger the scale of assessment, the coarser the resolution of data and hence the resultant information/advice on resource management that can be produced. For resource management, an essential consideration in relation to scale is that of environmental governance (Görg, 2007; Padmanabhan and Jungcurt, 2012). Most land is managed at parcel (field) scales with broader governance structures, where they exist, effective at local to national scales. Governance with an ES agenda may be increasingly widespread following the MA (Millenium Ecosystem Assessment, 2005) but little research has been done to inform land managers (and those institutions with the responsibility for ensuring large scale ES provision) about optimal landscape scale management for the delivery of ES (Hassan et al., 2005).

The scale at which science is carried out tends to be prescribed by the constraints imposed by funding mechanisms and their required deliverables. Most natural science studies focus either on the micro-scale, and study a reduced set of variables with relatively high control, or focus on the landscape scale using large amounts of data collected over a wide range of sites to identify effects/trends (Bilotta et al., 2010; Boix-Fayos et al., 2009; Collins et al., 2007). The potential value of socio-ecological landscape scale approaches, which take into account human impacts on and use of ES, is increasingly recognised by natural scientists and others (Potschin and Haines-Young, 2006; Görg, 2007). Despite this, many gaps remain in our understanding of the interactions between ecosystems and with humans because relatively little science which incorporates both natural and social science perspectives (interdisciplinary science) is actually done in this area.

Recognition of the lack of studies which could provide valuable insight into how interactions between humans and ecosystems impact on the delivery of services from ecosystems has led to research initiatives which seek to promote interdisciplinary approaches. These include the Rural Economy and Land Use (RELU) programme (Lowe and Phillipson, 2006) under which the Loweswater work described here was conducted. Another key pillar of the RELU programme, recognising the role that publics play in environmental decision making (Lowe and Phillipson, 2006), was stakeholder engagement. 'Stakeholder' covers a wide range of potential participants in research, from individual land owners to national policy makers and wider publics affected by environmental decision making. Increasingly stakeholder engagement is recognised as an important facet of studies investigating and attempting to address socio-ecological issues (Krueger et al., 2012), reflecting the role of stakeholders in environmental management at multiple scales. In the development of ES measures, understanding human interactions with the environment and the roles of stakeholders therein are intrinsically connected to 'place' (Berkes, 2004; Lowe et al., 2009; Fish et al., 2010; Waterton et al., 2015). For example, the provision and enjoyment of clean water in a catchment needs to take into account those impacting on and using the water, rather than assessing land and water quality in that catchment independently of human interactions.

Problems associated with specific localities or 'places' tend to require approaches which reflect the specific social and natural composition of the locality. Methods currently used to derive ecosystem indicators vary widely with some focusing on modelling at field/experimental scales (Lavelle et al., 2014; Williams and Hedlund, 2014) and many others at regional/national scales (Maes et al., 2012; Locatelli et al., 2014). The extent to which indicators developed at large scales translate to particular localities has not been widely investigated. Similarly comparisons to highlight the constraints and benefits of working at different scales, and their impacts on the value of the ES indicators developed, are rare.

This paper seeks to address this issue by carrying out and then contrasting alternative approaches to providing indicators of ES delivery at different scales, focusing particularly on the interactions between land management and water quality indicators, but also incorporating a wider range of service indicators, where practical. The work on which it is based was developed in response to a political and scientific desire to understand the important factors influencing the value of ES indicators related to the scale at which they are produced. The study focuses on data from two 'sites': (1) Great Britain (GB), as sampled by the Countryside Survey, a national long term monitoring programme (Norton et al., 2012) and (2) the Loweswater catchment in the English Lake District, as sampled by the Loweswater Rural Economy and Land Use (RELU) study. The former study takes an integrated ecological sampling approach at a representative sample of GB sites on an 8–10 year cycle (5 surveys since 1978). The Loweswater study was an interdisciplinary, stakeholder engaged active research project to investigate approaches to community catchment management in a catchment suffering from poor water quality. Modelling approaches described here build on previous work exploring the provision of clean water at the two 'sites' using water quality indicators (Dunbar et al., 2010 – Countryside Survey and Norton et al., 2011b – Loweswater). Previous approaches include process based modelling and mixed effects linear models, whilst new approaches described here include the use of Bayesian Network (BN) analysis and Boosted Regression Tree (BRT) modelling. Bayesian networks are now widely used to model environmental systems due to their capacity for integrating multiple issues and investigating trade-offs (Barton et al., 2008; Chen and Pollino, 2012), such as those between water quality and food production. Understanding how the production of one ES may trade-off against another is important when making decisions for sustainable ES delivery. In contrast to BN's, Boosted Regression Tree models are a relatively new approach to modelling large and complex ecological data sets. They include features which are highly suitable for typical characteristics of ecological data (complex, non-linear relationships, non-normality, missing data, variable data formats and inter-correlated predictor data).

The new models were used to explore the limits of the available data in order to gain an understanding about the importance of scale and approach, from both modelling and data collection perspectives, to what we can learn about ES indicators. The approaches are compared systematically in terms of how scale impacts on: (a) the data required, (b) the extent to which the approaches conceptualise the socio-ecosystems under study, (c) the ecosystem indicators produced and on (d) the potential relevance of the approaches to land managers, institutional frameworks and policy makers.

2. Methods

The methods used in this paper consist of two parts. The first (modelling approaches) describes the construction of the two modelling approaches used to provide ES indicators at two different scales. The second (comparative approaches) describes the comparison between the two approaches in terms of scale and associated factors.