Ecological Economics 110 (2015) 15–27

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Methodological and Ideological Options

Operationalizing an ecosystem services-based approach using Bayesian Belief Networks: An application to riparian buffer strips

Alistair McVittie [a,*], Lisa Norton [b], Julia Martin-Ortega [c], Ioanna Siameti [a], Klaus Glenk [a], Inge Aalders [c]

[a] Scotland's Rural College (SRUC), West Mains Road, Edinburgh, United Kingdom
[b] Centre for Ecology and Hydrology, Lancaster Environment Centre, Lancaster, United Kingdom
[c] James Hutton Institute, Aberdeen, United Kingdom

ARTICLE INFO

Article history:
Received 13 January 2014
Received in revised form 27 November 2014
Accepted 18 December 2014
Available online 8 January 2015

Keywords:
Bayesian networks
Ecosystem services
Interdisciplinary research
Valuation

ABSTRACT

The interface between terrestrial and aquatic ecosystems contributes to the provision of key ecosystem services including improved water quality and reduced flood risk. We develop an ecological–economic model using a Bayesian Belief Network (BBN) to assess and value the delivery of ecosystem services from riparian buffer strips. By capturing the interactions underlying ecosystem processes and the delivery of services we aim to further the operationalization of ecosystem services approaches. The model is developed through outlining the underlying ecological processes which deliver ecosystem services. Alternative management options and regional locations are used for sensitivity analysis.

We identify optimal management options but reveal relatively small differences between impacts of different management options. We discuss key issues raised as a result of the probabilistic nature of the BBN model. Uncertainty over outcomes has implications for the approach to valuation particularly where preferences might exhibit non-linearities or thresholds. The interaction between probabilistic outcomes and the statistical nature of valuation estimates suggests the need for further exploration of sensitivity in such models. Although the BBN is a promising participatory decision support tool, there remains a need to understand the trade-off between realism, precision and the benefits of developing joint understanding of the decision context.

1. Introduction

Recent years have seen the growing adoption of ecosystem services-based approaches for analysis and decision-making with respect to the environment. This approach has also encouraged the development of a common language across natural and social science disciplines that in turn has led to joint analysis and assessments. Notable examples of the latter include the Millennium Ecosystem Assessment (MA, 2005) and the UK's National Ecosystem Assessment (UK NEA, 2011). However, the increasing prevalence of interdisciplinary analysis has highlighted the need to further develop common models and tools to explore our joint understanding of ecosystem services that might better inform management and policy (Martin-Ortega et al., 2015). This is the key issue in the operationalization of ecosystem services as an analytical and decision making approach. To this end there have been some targeted attempts to foster interdisciplinary working, such as the UK's Valuing Nature Network,[1] which specifically seeks to promote research capacity on the integration of approaches to the valuation of ecosystem services to support policy and practice.

The complexities and interdependencies among components within and between ecosystems make describing and quantifying interactions within and across ecosystems a considerable challenge (Heal et al., 2001; Pereira et al., 2005; Carpenter et al., 2009; Maskell et al., 2013). Multiple ecological mechanisms interact within ecosystems resulting in the delivery of single or multiple services; or a single mechanism may contribute to multiple ecosystem services. The provision of ecosystem services may also be dependent on the contributions of many different ecosystems (Defra, 2007), for example good water quality arises from both terrestrial and aquatic ecosystems. Hence, policy decisions affecting any part of those interactions can cause changes across multiple services and ecosystems. Given this complexity, from an economic perspective the value of any ecosystem service may then be determined by its relationship with other services (UK NEA, 2011).

NRC (2005) reviewed studies attempting to integrate ecological and economic knowledge to value either single or multiple ecosystem services, concluding that our inability to estimate the 'true' value of ecosystem services is mainly associated with three factors: i) lack of ecological understanding of how ecosystem services are being affected by alternative management practices, ii) inadequacy of the existing economic techniques to quantify the 'true' value of multiple ecosystem services,

* Corresponding author.
E-mail address: alistair.mcvittie@sruc.ac.uk (A. McVittie).

[1] The VNN is a UK Natural Environment Research Council funded initiative aimed at bringing together natural and social scientists, economists, policy-makers and business interests. http://www.valuing-nature.net/.

http://dx.doi.org/10.1016/j.ecolecon.2014.12.004
0921-8009/

and iii) inability to integrate ecological and economic knowledge. In order to tackle the methodological challenges of valuing ecosystem services, there is a growing consensus that integrated studies should be undertaken, which account for the interactions and non-linear relationships among ecosystem components (Carpenter et al., 2009; Kremen and Ostfeld, 2005; Tallis and Kareiva, 2005; Turner et al., 2003). Many authors suggest that it is necessary to develop a more holistic (Turner and Daily, 2008), interdisciplinary valuation approach that integrates economic and ecological knowledge (Brauman et al., 2007; Hein et al., 2006; O'Riordan and Stoll-Kleemann, 2002; Pagiola et al., 2004). In other words, there is need for an approach that could quantify the economic value of the 'ecosystem service cascade' proposed by Haines-Young and Potschin (2009), integrating the underlying linkages between services and processes to provide a more accurate estimate of the ecosystem value.

A common problem with developing interdisciplinary models and tools has been to integrate different scientific and social science disciplines that operate at varying degrees of complexity. Biophysical science approaches to ecosystems operate over a wide range of scales and complexities including very context specific field studies (Norton et al., 2012a). Socio-economic approaches, such as non-market valuation, are often broad-brushed to avoid overburdening survey respondents, whose values we seek, with complex information. Relevant economic data are also often only available at large scales (e.g. national or regional). Neither of these scales may match policy or decision-making. Consequently, there is a potential mismatch of complexity and scales in the use of extant models and data. In order to operationalize an ecosystem services-based approach researchers and decision makers may need to develop joint models where we explicitly sacrifice precision in disciplinary approaches to achieve outcomes that are still of use to decision making.

In this paper we present an interdisciplinary approach based on Bayesian Belief Networks (BBN) in the hope of provoking discussion and debate about the virtues and limitations of BBNs as a tool to address some of the integration challenges. The benefit of using BBNs in natural resource management is their usefulness for predicting the links between management practices and ecosystem reactions (Clark et al., 2001; Borsuk et al., 2004), whilst they can also deal with a large number of interconnected data and integrate different types of variables (e.g. environmental, economic, social and physical variables) or knowledge from diverse sources (Bromley et al., 2005). In fact, BBNs have been widely applied in environmental studies including fisheries assessment (Kuikka et al., 1999; Lee and Rieman, 1997; Pollino et al., 2007); forest restoration (Haas et al., 1994); climate change problems (Gu et al., 1996; Kuikka and Varis, 1997); habitat restoration (Rieman et al., 2001); watershed management (Hamilton et al., 2007; Ames et al., 2005; Borsuk et al., 2004; Bromley et al., 2005; Henriksen et al., 2004) and nitrogen pollution impacts on wetland ecosystem services (Spence and Jordan, 2013). The review by Landuyt et al. (2013) indicates the excellent conceptual fit between the structure of BBN's and the ecosystem service production cascade (Haines-Young and Potschin, 2009), but alludes to limited attempts in the literature to exploit the potential of BBN's for elucidating the cascade in particular cases of ecosystem service delivery. Haines-Young (2011) uses two case studies from the UK NEA to explore how BBNs could be used to operationalize different components of the cascade model. This paper seeks to develop this approach by explicitly analysing the effects of one management mechanism (riparian buffer strips) on the delivery of ecosystem services (in the UK NEA example used by Haines-Young, different land cover scenarios are explored but not linked to management mechanisms). Landuyt et al. (2013) note, that BBNs have particular value because of the capacity for using them to consider the delivery of multiple ecosystem services whilst allowing the integration of multidisciplinary knowledge. However, they conclude that the integration of decision nodes and valuation into Bayesian networks remains an important challenge; this paper attempts to address that challenge.

The BBN was developed through a series of workshops under the Valuing Nature Network involving natural and economic scientists interested in identifying approaches for valuing the provision of ecosystem services across agricultural and aquatic ecosystems. The choice to focus on water quality and flood risk was based on workshop discussions around these two high profile services which are a focus of policy with respect to the European Water Framework Directive and Floods Directive. Buffer strips were identified as a relevant management instrument, widely employed through various agri-environment schemes for precisely the delivery of those services (Doody et al., 2012; Haygarth et al., 2009), and used here as a test case. We recognise that buffer strips offer a far wider range of services (Stutter et al., 2012) but in recognition of the potential complexity of valuing all these services, we have focused on the water services only. In the following section we discuss the issue of complexity and interactions in ecosystem service analysis and subsequent economic valuation in the context of the approach adopted. We then outline our approach before describing its specific application to riparian buffer strips. Finally we discuss outputs from this model and its further potential development.

2. Ecosystem Service Valuation — Complexity, Interactions and Scale

As Boyd and Banzhaf (2007) argue, there should be a clear distinction between the 'final ecosystem services' that are directly consumed by individuals and the 'intermediate ecosystem functions' or processes that contribute to their delivery. Ecological processes are considered the intermediate biological, physical and chemical interactions between ecosystem services, rather than end-products. For instance, nutrient cycling and water flow are ecological functions which interact to deliver the service of water quality alongside other ecosystem services. Haines-Young and Potschin (2009) use the idea of a 'service cascade' to illustrate the mechanisms that underpin the connections between ecological assets and welfare, and the series of intermediate stages in which they are linked (Fig. 1). This service cascade serves as the basic template for building the BBN in this study.

In the context of environmental valuation, the classification of ecosystem services into 'intermediate processes', 'final services' and 'benefits' addresses the problem of 'double counting' the values of ecosystem services (Boyd and Banzhaf, 2007; Fisher and Turner, 2008; Fisher et al., 2009; Fu et al., 2011; Ojea et al., 2012). For instance, in the case of a wetland, the intermediate functions of nutrient cycling and water regulation interact to deliver clean water. The actual benefit that humans derive from water provision may include recreation (e.g. angling, swimming, seeing water in the context of a landscape (Norton et al., 2012b)) or potable water (Fisher et al., 2009). Although it seems sensible to value the consumed products (tangible or intangible), the ability to acknowledge and measure the extent to which the processes underlying their delivery contribute to the final value of benefits is vital. Only in this way, can policy decisions affecting environmental management be valued for their impact on ecosystem services and ultimately the delivery of ecosystem benefits. It is therefore important that integrated models reflect relationships between final services, underlying processes and generated benefits.

In general, ecosystem service valuation tends to focus on one service at a time (Turner et al., 2003), disregarding interactions between ecosystem functioning and services. This is in part influenced by the difficulties faced by ecosystem science in considering multiple ecosystem service delivery, although it is acknowledged that such an approach is essential for the sustainable management of natural systems (NRC, 2005; Diaz and Rosenberg, 2008; Gordon et al., 2008). In addition, the available approaches to undertake economic valuation of ecosystem services may themselves be inadequate for encompassing the complexities of natural systems. Valuation approaches vary in the extent to which they directly value individual or combinations of ecosystem services. Stated preference studies, either by virtue of the constructed valuation scenario or the good being valued (e.g. public goods and/or