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Conceptual advancement of socio-ecological modelling of ecosystem services for re-evaluating Brownfield land

B.W. Kolosz[a,b,*], I.N. Athanasiadis[c], G. Cadisch[d], T.P. Dawson[e], C. Giupponi[f], M. Honzák[g,h], J. Martinez-Lopez[i], A. Marvuglia[j], V. Mojtahed[k], K.B.Z. Ogutu[l,m], H. Van Delden[n,o], F. Villa[i], S. Balbi[i]

[a] *School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK*
[b] *Research Centre for Carbon Solutions, Heriot-Watt University, Riccarton, UK*
[c] *Information Technology Group, Wageningen University, Wageningen, The Netherlands*
[d] *Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute), University of Hohenheim, Stuttgart, Germany*
[e] *Geography Department, King's College London, King's College, 5 Strand Lane, London, UK*
[f] *Department of Economics, Ca' Foscari University of Venice, Cannaregio 873, 30121 Venice, Italy*
[g] *Betty and Gordon Moore Center for Science, Conservation International, 2011 Crystal Drive, Suite 500, Arlington, VA 22202, USA*
[h] *Center for Biodiversity Outcomes, Arizona State University, PO Box 875402, Tempe, AZ 85287, USA*
[i] *Basque Centre for Climate Change (BC3), Scientific Campus of the University of the Basque Country, 48940 Leioa, Bilbao, Spain*
[j] *Luxembourg Institute of Science and Technology (LIST), Environmental Research and Innovation (ERIN) Department, 41 rue du Brill, L-4422, Belvaux, Luxembourg*
[k] *Fera Science, National Agri-food Innovation Campus, Sand Hutton, York, UK*
[l] *Department of Mathematics & Physical Sciences, School of Science, Dedan Kimathi University of Technology, P.O Box 657-10100, Nyeri, Kenya*
[m] *LMD/IPSL, Ecole normale supérieure, PSL Research University, Ecole polytechnique, Université Paris-Saclay, Sorbonne Universités, UPMC Univ Paris 06, CNRS, 24 rue Lhomond, 75005 Paris, France*
[n] *Research Institute for Knowledge Systems (RIKS), Hertogsingel 11B, 6211 NC Maastricht, The Netherlands*
[o] *School of Civil, Environmental and Mining Engineering, The University of Adelaide, Adelaide, SA 5005, Australia*

ABSTRACT

Essential environmental resources are rapidly exploited globally, while social-ecological systems at different scales fail to meet sustainable development challenges. Ecosystem services research, which at present predominantly utilizes static modelling approaches, needs better integration with socio-economic dynamics in order to assist a scientific approach to sustainability. This article focuses on Brownfield lands, a unique landscape that is undergoing transformations and provides ecosystem services that remain, at this point in time, mostly unrecognized in public discourse. We discuss the main issues associated with current modelling and valuation approaches and formulate an ecosystem-based integrated redevelopment workflow applied to the assessment of Brownfield redevelopment options.

1. Introduction

Ecosystem services (ES) have acquired increasing attention in public discourse over the last 20 years and are today broadly understood through the lenses of well-established classification frameworks, e.g. the Millennium ecosystem Assessment (2005). Derived conceptual models and mapping methods have improved environmental accounting and started to scratch the surface of a complex research field that feeds on an interdisciplinary research landscape (Haddad et al., 2017, Mota-López et al., 2018, Brudvig et al., 2017). However, their role in practical decision making – either by governments or businesses - has progressed little despite such advancements.

Since the Millennium Ecosystem Assessment (2005) and the first classification of ES, the field has grown considerably, including the development of capabilities for decision support. Decision support protocols were developed and applied which include a recognition of intermediate services, phases and benefits (Fisher et al., 2009). Focus was then broadened to include sustainability-oriented approaches for the governance of natural resource management, with consideration of multiple systems and agents within systems (Ostrom, 2009). These conceptual frameworks aimed to determine the behaviour of environmental change on ES. For example, several frameworks for ES provision were developed with social-ecological systems (SES) in mind, focusing on the combination of human and natural factors affecting human well-being (Reyers et al., 2013). Others emphasized the response of human societies, integrated within social-ecological systems, by means of an enhanced driver-pressure-state-impact-response (DPSIR) framework (Rounsevell et al., 2010, Nassl and Löffler, 2015), capturing the

* Corresponding author at: Research Centre for Carbon Solutions, Heriot-Watt University, Riccarton, UK.
E-mail address: b.kolosz@hw.ac.uk (B.W. Kolosz).

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feedbacks of anthropogenic environmental changes to the ecosystems' capacity.

The need to strike a balance between the provision of multiple environmental goods and services and the demand of a rapidly growing society led to the introduction of supply and demand scenarios, considering ecosystem integrity and their contributions and health effects on humanity (Burkhard et al., 2012). Conceptual frameworks for analysing ES delivery included potential capacity and flows as well as the role of social preferences (Villamagna et al., 2013). Higher-level conceptual frameworks posed more emphasis on sustainability at the global scale, illustrating distant interactions, i.e. teleconnections (Seto et al., 2012), including the role of trade (Liu et al., 2013, Rockstrom et al., 2009). Recent methodologies for adaptable and robust ES assessment highlight the need for data and model integration (Villa et al., 2014) for capturing the whole complexity that characterizes ES.

In this paper we propose an operational, integrated nature-society-economy workflow for Brownfield land redevelopment and prioritisation. Brownfield land systems, where land was previously used for industrial purposes, are an interesting case to discuss because of their complex interactions with ES. Furthermore, Brownfield land has unique features and large variability that benefit from an integrated nature-society-economy approach: it is a type of land that is constantly undergoing dynamic transformations, impacting on the provision of ES. Such services are in fact imperceptible to the public, hidden behind the overwhelming negative visual impact of many Brownfield land sites. Therefore, successful integration between stakeholder beliefs and recommendations requires new methods that can capture their thoughts and prioritise which ES would be appropriately beneficial to Brownfield land and to the local community. Section 2 illustrates the authors' perceived main challenges of the modelling and evaluation of ES. Section 3 conceptualises the problem of Brownfield redevelopment under the ES perspective and Section 4 introduces an integrated redevelopment workflow detailing how to prioritise ES depending on the original function and location of Brownfield land.

2. Current challenges in modelling and valuing ecosystem services

2.1. Current limitations of ecosystem services modelling

ES have gained increased visibility especially from a socio-economic standpoint: the quantification of such services adds valuable information for the selection and evaluation decisions concerning the planning of certain categories of land, such as Brownfields.

Two main limitations associated with the assessment and quantification of ES relate to the understanding and modelling of (1) the capacity of different ecosystems to provide a bundle of varied services, and (2) the unpredictability of tipping points in service delivery. These are affected by both ecosystem dynamics and human activities such as overexploitation and/or the rise of new technologies, as is the case of increased input contribution into agricultural production (Lippe et al., 2011). Both phenomena are characterized by high complexity and deep uncertainty (Hannart et al., 2013) and their study should involve multidisciplinary and transdisciplinary science and technology (Chen et al., 2017). At the same time, they should involve an exploratory modelling approach that can make use of different models (of the same service) in order to capture uncertainties, as done for example in weather forecast practice (Krishnamurti et al., 1999), or in climate change sciences, which uses model ensembles. Therefore, the developing and modelling of future scenarios and trade-off analyses should also be part of the assessment.

2.2. Ecosystem services inter-linkages and trade-offs

A variety of challenges limit the effectiveness of ES modelling approaches. In particular, disciplinary boundaries hamper a full study of the effects of human behaviour on ecosystems. For example, theories and models should represent the behaviour of humans in relation to nature, in order to predict adaptive and flexible responses to changes to the environment. Conceptual models currently exist outside the ES domain which can better cater for such non-linear decision making, such as Ostrom's (2009) social-ecological systems model. Various human-based entities, such as organisations and small companies, must be included as part of a theory of evidence which constitutes the perceptions of all stakeholders involved in prioritising ES multi-functionality within certain contexts of land use and cover change (Berbés-Blázquez et al., 2016).

Much interest has focused on the implementation of indicators to assess the status of biodiversity and key ecosystem functions from local to global scales (European Commission et al., 2012, Singh et al., 2006, Steffen et al., 2015, Kumar, 2010, Cotter et al., 2017). However, assessing human impacts on the structural integrity of ecosystems (as well as the other way around), their capacity to supply services, their vulnerability and resilience, remains a challenge. So far, consensus is lacking on the methodological tool(s) used to incorporate inter- and intra-relationships and feedback across the many causal paths and links between nexuses (see Liu et al., 2015). This renders a definition of priorities to support policies at different scales difficult. To this end, scientists have been working on the development of integrated modelling tools to assess the contribution of ecosystems to human activities (see Bagstad et al. (2013) for a review). In the case of commodity productions, we refer to system dynamics, such as the global unified meta-model of the biosphere (Boumans et al., 2002), later advanced by (Arbault et al., 2014) and then proposed to build a dynamic approach to value ES with the multi-scale integrated model of ES (MIMES: (Boumans et al., 2015)). However, most of Earth system dynamics modelling tools are very coarse in their capability to represent human decision making and thus very far away from representing fine-grained social dynamics. A more effective framework, in this sense, can be based on the combination of agent-based modelling, Bayesian belief networks and opinion dynamics models (Sun and Müller, 2013). Agent-based models are suited to represented complex systems, and in particular, the heterogeneity of their components, the dynamic interactions among them, and the emergence of organizational structures (Balbi and Giupponi, 2010). Bayesian belief networks help in describing the human decision making process by exploring conditional probabilities of cascades of actions or events. Such models — empowered by opinion dynamics models to explain social influence — are used to simulate the actions enabled by decisions, and thereby improve the understanding of socio-ecological systems.

The simultaneous modelling of multiple ES is also a challenge (Bennett et al., 2009) and remains a rather unaddressed topic in the literature (Nemec and Raudsepp-Hearne, 2013), due to data limitations, complexity of the phenomena and methodological gaps (Mach et al., 2015). Services are frequently interwoven and incentives boosting the valorisation of one service may adversely impact other services (Foley et al., 2005, Kinzig et al., 2011). Some recent studies have investigated commonalities and trade-offs among ES (Gonzalez-Redin et al., 2016, Jia et al., 2014, Jopke et al., 2015, Kirchner et al., 2015, Qiu and Turner, 2013, Ruijs et al., 2013, Van der Biest et al., 2014, Balbi et al., 2015, Lee and Lautenbach, 2016, Turner et al., 2014) but the quantification of their interlinkages and the formulation of an explicit functional relationship have not yet been fully achieved. It may in fact be necessary to prioritise a small subset of ecosystems to one specific piece of land as opposed to attempt to squeeze all ES into a single space (Watts et al., 2009, Gómez-Baggethun and Barton, 2013). This procedure of evaluation and prioritisation, already tested for the planning of protected areas using tools such as Marxan (Watts et al., 2009, Ball et al., 2009) will allow special types of areas to be developed. These areas can then be given an identity and a sense of purpose, questioning the objectives of local development and ES valorisation so that the public can acknowledge what is trying to be achieved not only within