Global Environmental Change 47 (2017) 37–50

Contents lists available at ScienceDirect

Global Environmental Change

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

Unpacking ecosystem service bundles: Towards predictive mapping of synergies and trade-offs between ecosystem services

Rebecca Spake[a,b], Rémy Lasseur[c], Emilie Crouzat[c], James M. Bullock[d], Sandra Lavorel[b,c], Katherine E. Parks[e], Marije Schaafsma[a,b], Elena M. Bennett[f], Joachim Maes[g], Mark Mulligan[h], Maud Mouchet[i], Garry D. Peterson[j], Catharina J.E. Schulp[k], Wilfried Thuiller[b,c], Monica G. Turner[l], Peter H. Verburg[k,m], Felix Eigenbrod[a,b,*]

[a] Biological Sciences, University of Southampton, Southampton SO17 1BJ, UK
[b] Geography and the Environment, University of Southampton, Southampton SO17 1BJ, UK
[c] Laboratoire d'Ecologie Alpine, CNRS – Université Grenoble Alpes, CS 40700, 38058 Grenoble Cedex 9, France
[d] NERC Centre for Ecology and Hydrology, Maclean Building, Benson Lane, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK
[e] Centre for Environmental Science, Faculty of Engineering and the Environment, University of Southampton, Southampton SO17 1BJ, UK
[f] Department of Natural Resource Sciences and McGill School of Environment, McGill University, Ste. Anne-de-Bellevue, QC, 21111 Lakeshore H9X3V9, Canada
[g] European Commission, Joint Research Centre, Via E. Fermi, 2749, 21027 Ispra, VA, Italy
[h] Environmental Dynamics Research Group, Department of Geography, King's College London, Strand, London, WC2R 2LS, UK
[i] UMR 7204 MNHN-UPMC-CNRS Centre d'Ecologie et des Sciences de la Conservation, CP135, 43 rue Buffon, 75005 Paris, France
[j] Stockholm Resilience Centre, Stockholm University, Kr€aftriket 2B, SE-106 91 Stockholm, Sweden
[k] Environmental Geography, Department of Earth Science, VU University Amsterdam, De Boelelaan, 1081 HV Amsterdam, The Netherlands
[l] Department of Zoology, University of Wisconsin, Madison, WI 53706, USA
[m] Swiss Federal Research Institute WSL, Research Unit Landscape Dynamics, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland

ARTICLE INFO

Keywords:
Cross-study comparison
Ecosystem services
French Alps
Land use
Social-ecological systems
Trade-off
Natural capital
Biodiversity

ABSTRACT

Multiple ecosystem services (ES) can respond similarly to social and ecological factors to form bundles. Identifying key social-ecological variables and understanding how they co-vary to produce these consistent sets of ES may ultimately allow the prediction and modelling of ES bundles, and thus, help us understand critical synergies and trade-offs across landscapes. Such an understanding is essential for informing better management of multi-functional landscapes and minimising costly trade-offs. However, the relative importance of different social and biophysical drivers of ES bundles in different types of social-ecological systems remains unclear. As such, a bottom-up understanding of the determinants of ES bundles is a critical research gap in ES and sustainability science.

Here, we evaluate the current methods used in ES bundle science and synthesize these into four steps that capture the plurality of methods used to examine predictors of ES bundles. We then apply these four steps to a cross-study comparison (North and South French Alps) of relationships between social-ecological variables and ES bundles, as it is widely advocated that cross-study comparisons are necessary for achieving a general understanding of predictors of ES associations. We use the results of this case study to assess the strengths and limitations of current approaches for understanding distributions of ES bundles. We conclude that inconsistency of spatial scale remains the primary barrier for understanding and predicting ES bundles. We suggest a hypothesis-driven approach is required to predict relationships between ES, and we outline the research required for such an understanding to emerge.

* Corresponding author at: Felix Eigenbrod, Geography and Environment, University of Southampton, Southampton SO17 1BJ, UK.
E-mail addresses: r.spake@soton.ac.uk (R. Spake), remy.lasseur@gmail.com (R. Lasseur), emiliecrouzat@gmail.com (E. Crouzat), jmbul@ceh.ac.uk (J.M. Bullock), sandra.lavorel@ujf-grenoble.fr (S. Lavorel), k.e.parks@soton.ac.uk (K.E. Parks), m.schaafsma@soton.ac.uk (M. Schaafsma), elena.bennett@mcgill.ca (E.M. Bennett), joachim.maes@jrc.ec.europa.eu (J. Maes), mark.mulligan@kcl.ac.uk (M. Mulligan), maud.mouchet@mnhn.fr (M. Mouchet), garry.peterson@su.se (G.D. Peterson), nynke.schulp@vu.nl (C.J.E. Schulp), wilfried.thuiller@ujf-grenoble.fr (W. Thuiller), turnermg@wisc.edu (M.G. Turner), peter.verburg@vu.nl (P.H. Verburg), F.Eigenbrod@soton.ac.uk (F. Eigenbrod).

http://dx.doi.org/10.1016/j.gloenvcha.2017.08.004
Received 9 September 2016; Received in revised form 28 July 2017; Accepted 7 August 2017
Available online 04 October 2017
0959-3780/

1. Introduction

Current understanding of how multiple ecosystems services (ES) are associated across heterogeneous landscapes remains limited (Bennett et al., 2009; Qiu and Turner, 2013; Turner et al., 2013; Bennett et al., 2015). This understanding is essential for informing better management of multi-functional landscapes. Although the idea that the spatial distribution of ES and their associations are driven by the interplay between social and ecological variables is well-established (Reyers et al., 2013), the relative importance of different social and biophysical drivers of sets of ES and how these change across different socio-ecological systems remains unclear (Bennett et al., 2015). Consequently, there have been calls to achieve a greater understanding of the drivers of ES distributions and associations (Bennett et al., 2009; Howe et al., 2014; Bennett et al., 2015).

Associations among ES are understood to occur when multiple services respond to the same driver of change or ecological process, or when interactions among the services themselves cause changes in one service to alter the provision of another (Bennett et al., 2009). Such associations are commonly referred to as ES interactions (Raudsepp-Hearne et al., 2010), with synergies and trade-offs being routinely explored in multi-ES assessments (Howe et al., 2014). Synergies arise when multiple services are enhanced simultaneously, while trade-offs occur when the provision of one service is reduced due to increased use of another. While ES associations can be highly context-specific (Howe et al., 2014), there have been calls for the development of general rules about the relationships among ES (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). In attempting to distinguish ES associations that are context-specific from those that are universal, several authors have emphasised the need for cross-study comparisons (e.g. Bennett et al., 2009; Raudsepp-Hearne et al., 2010; Meacham et al., 2015). However, cross-study comparisons are hampered by differences in approaches, the services covered, spatial scale, how ES are modelled and what drivers are used (Grêt-Regamey et al., 2014; Queiroz et al., 2015).

The concept of 'ecosystem service bundles' has been operationalised to help in the search for general rules determining ES associations (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). While rather confusingly the use of the term varies in the literature, with bundles and synergies used interchangeably (Berry et al., 2015; see Box 1 for definitions used here), the term has been widely used in conjunction with the application of a spatially explicit framework developed by Raudsepp-Hearne et al. (2010) for identifying and mapping ES associations based on cluster analysis. Raudsepp-Hearne et al. (2010) defined ES bundles as coherent sets of ES repeatable in space or time. This clustering approach has been applied across the world to facilitate cross-study comparisons of ES associations and their drivers (Table 1 and Fig. 1). Maps of ES bundles delineated with this approach can indicate what services can be expected to associate based on where we find services repeatedly occurring together across a landscape (Raudsepp-Hearne et al., 2010). Their distributions have been typically interpreted with regards to known distributions of principal human activities or land use within the region (Table 1) and are therefore considered useful for communicating the potential impact of management decisions to policy-makers (Crouzat et al., 2015). This qualitative interpretation of ES bundle distribution provides some information about the drivers of ES associations and whether different social-ecological systems have particular sets of ES associated with them (Bennett et al., 2009). In addition to qualitative interpretation of ES bundles, recent studies have attempted a more mechanistic approach to understanding ES bundle distribution, based on the relative roles of different social-ecological drivers, with multi-variate approaches being increasingly used (Mouchet et al., 2014). Raudsepp-Hearne et al. (2010) suggested that spatially explicit analyses of the social-ecological variables driving ES bundles could ultimately allow for the prediction and modelling of ES bundles and thus, critical trade-offs and synergies across regions (Raudsepp-Hearne et al., 2010). Studies that aim to achieve such an understanding typically infer ES associations from the analysis of spatial trends in the distribution of two or more ES, and relate these to underlying social-ecological determinants (Mouchet et al., 2014). Further, if widely accessible data on social-ecological drivers (such as land use and population density) can predict ES bundles, this could potentially overcome problems associated with complex and data-intensive models that are required to produce ES maps (Meacham et al., 2015). Indeed, an ability to use limited variables to inform about the ES context is particularly important in data scarce regions (Meacham et al., 2016).

Here, we critically assess the strengths and limitations of current approaches for explaining and/or predicting the distribution of spatial associations between multiple ES. Most studies of this type to date follow the spatially explicit ES bundle approach first outlined by Raudsepp-Hearne et al. (2010) (Table 1). We first review studies that have applied this approach (Table 1 and Fig. 1) and synthesize the application of it into four steps (Fig. 2), that capture the plurality of methods currently used, and illustrate them with a case study – a cross-study comparison of the North and South regions of the French Alps. We then use the outcomes of this case study to assess the strengths and limitations of current approaches for linking social ecological drivers to ES bundles. Finally, we outline a roadmap for research required to enable a general understanding of ES associations.

2. Current approaches to understanding spatially explicit ES associations

2.1. Step 1: assessment, aggregation and harmonisation of ecosystem service indicators

Studies that have examined drivers of spatial ES bundles exhibit considerable variation regarding the number and types of ES considered, and in how individual ES are quantified (Table 1). Studies have typically considered a relatively large number of ES (averaging ∼12 ES), encompassing a range of provisioning, regulating and cultural ES, and also biodiversity metrics (Table 1). Contrasting large numbers of ES within different ES categories can contribute to a better understanding of ES trade-offs (Raudsepp-Hearne et al., 2010; Crossman et al., 2013).

ES maps often vary in the units, range of output values, and spatial resolution. To enable bivariate or multivariate analyses, ES datasets have been aggregated to a common resolution. While studies have mapped ES at scales ranging from local to global (see Crossman et al., 2013 and Malinga et al., 2015 for recent reviews), studies mapping ES bundles tend to be conducted for parts of countries at the spatial resolution of administrative boundaries, typically the smallest political units such as municipalities (Table 1). The use of administrative boundaries has been advocated as relevant for multi-ES studies (Raudsepp-Hearne et al., 2010), as municipalities represent the smallest scale of governance (in most areas of Europe) where many decisions regarding planning and landscape management are taken (Hamann et al., 2015; Queiroz et al., 2015). The selected grain for multi-ES research is also likely to have been driven by data availability; municipalities often are the finest scale at which some ES (such as provisioning ES) and potential social data are available (e.g. census data). We consider the potential limitations of municipality-level analyses in the discussion.

Following collation and aggregation of multi-ES datasets, data are usually harmonised to a common range and unit to allow for comparison prior to data analysis. The methods used such as standardisation (transformation to z-scores by centring and scaling), serve to adjust the magnitude and variability of the variables to make them compatible for analysis (Legendre and Legendre, 2012).