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Mapping ecosystem services across scales and continents – A review

Rebecka Malinga [a,*], Line J. Gordon [a], Graham Jewitt [b], Regina Lindborg [c]

[a] Stockholm Resilience Centre, Stockholm University, 106 91 Stockholm, Sweden
[b] Centre for Water Resources Research, Umgeni Water Chair of Water Resources Management, University of KwaZulu-Natal, Private bag X01, Pietermaritzburg 3201, South Africa
[c] Landscape Ecology, Department of Physical Geography and Quaternary Geology, Stockholm University, 106 91 Stockholm, Sweden

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ABSTRACT

Tremendous progress in ecosystem service mapping across the world has moved the concept of ecosystem services forward towards an increasingly useful tool for policy and decision making. There is a pressing need to analyse the various spatial approaches used for the mapping studies. We reviewed ecosystem services mapping literature in respect to spatial scale, world distribution, and types of ecosystem services considered. We found that most world regions were represented among ecosystem service mapping studies and that they included a diverse set of ecosystem services, relatively well distributed across different ecosystem service categories. A majority of the studies were presented at intermediary scales (municipal and provincial level), and 66% of the studies used a fine resolution of 1 ha or less. The intermediary scale of presentation is important for land use policy and management. The fact that studies are conducted at a fine resolution is important for informing land management practices that mostly takes place at the scale of fields to villages. Ecosystem service mapping could be substantially advanced by more systematic development of cross-case comparisons and methods.

1. Introduction

Tools that allow for spatially explicit estimates of ecosystem services play an increasingly important role in land use planning and conservation (Burkhard et al., 2013). These tools have become important because supply and demand for ecosystem services are spatially explicit, spatially disconnected and vary across the world (Crossman et al., 2013). Various ecosystem service mapping approaches and tools have therefore been developed both within science, and for policy (e.g. Tallis and Polasky, 2009; Egoh et al., 2012; Maes et al., 2012; Bagstad et al., 2013; Crossman et al., 2013).

Mapping ecosystem services makes it possible to analyse the spatial configuration of multiple ecosystem services in landscapes and regions. It is therefore a useful tool to help guide land use planning and decision making for management at large scales, where multiple sectors, such as agriculture, urban areas, water resources, conservation and forestry intersect. In the scientific literature authors have for example used spatial mapping of ecosystem services to understand the congruence between ecosystem services and conservation objectives (Chan et al., 2006; Egoh et al., 2009; Willemen et al., 2013), and how the supply of ecosystem services changes spatially in response to land use change and other drivers (Lautenbach et al., 2011; Zhang et al., 2011; Bryan and Crossman, 2013). Others have analysed how multiple ecosystem services are bundled together in generating trade-offs and synergies in different landscapes (Raudsepp-Hearne et al., 2010, García-Nieto et al., 2013; Ruijs et al., 2013; Queiroz et al., 2015). Many authors have also linked the spatial estimates of ecosystem services with economic models and compared supply and demand of ecosystem services (Kroll et al., 2012; Bastian et al., 2013), estimated the overall economic value of the services (Guo et al., 2001), as well as economic cost and benefit of conservation in relation to ecosystem service generation (Naidoo and Ricketts, 2006; Liu et al., 2010; Palomo et al., 2013).

Despite the tremendous progress that has been made in mapping different aspects of ecosystem services, much of the approaches are still under development (Seppelt et al., 2011; Crossman et al., 2013; Kandziora et al., 2013; Schägner et al., 2013). The results arising from the different studies also need to be used with caution, since maps and spatially presented data are very effective communication tools and could mask the complexity of underlying processes and weaknesses of data, resulting in legitimacy issues (Hauck et al., 2013, Kandziora et al., 2013).

Several reviews on ecosystem service mapping have recently been published (e.g. Egoh et al., 2012; Martínez-Harms and Balvanera, 2012; Crossman et al., 2013), emphasizing that mapping so far

* Corresponding author. Tel.: +27 727780103.
E-mail addresses: rebecka.malinga@su.se (R. Malinga), line.gordon@su.se (L.J. Gordon), jewittg@ukzn.ac.za (G. Jewitt), regina.lindborg@natgeo.su.se (R. Lindborg).

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has primarily focused mainly on regulating services, and has used secondary data (rather than field data) linked to land use/land cover, soils, and vegetation. The reviews also illustrate that most mapping has been done at large spatial scales (regional and provincial), with limited attention to understanding of ecosystem service supply and demand across multiple scales (Burkhard et al., 2013).

One of the risks with a dominance of studies being presented at larger scales is that they can potentially contribute to the creation of a "binary view" of landscape management rather than seeing landscapes as continuous and heterogeneous (Fischer et al., 2008). This can have implications for how we approach land use planning in general. There is for example an ongoing scientific discussion related to land use planning often referred to as the "land sparing vs. land sharing debate" (Phalan et al., 2011; Fischer et al., 2014). The land sharing/sparing dichotomy focuses on whether conservation as well as productivity goals can be best met through an approach that "spares land" for biodiversity and conservation-related ecosystem services by maximizing productivity in a more limited part of the landscape (land sparing), or whether the landscape should be more heterogeneous with conservation and productivity goals intermixed (land sharing). Fisher et al. (2008) suggested that policies for land sharing required a more fine-grained understanding of landscapes and their ecosystem services that capture smaller scale heterogeneity. In contrast, land sparing approaches can be developed with less resolution and larger grain sizes.

In this paper we want to deepen the analyses of the spatial scales at which mapping of ecosystem services takes place by conducting a systematic review of papers that have spatially mapped ecosystem services. If most mapping does take place at larger scales, as indicated in previous reviews, this could potentially unintentionally enhance development of tools that pushes for land use planning based on land sparing perspectives. However, this also depends on the spatial resolution for data underpinning the different studies as a fine resolution can provide tools also for land sharing perspectives. Therefore we analyse both the grain (i.e. resolution) and the extent (i.e. total area mapped) of the different mapping studies in our review. The term 'mapping ecosystem services' in this paper refers to spatially explicit quantification of ecosystem services or their proxies. Since different services operate at different scales (Fremier et al., 2013) we also look what services have been mapped at the different extents. For background we also map out where in the world ecosystem service mapping has been conducted, and what land uses dominate the study areas.

2. Methods

2.1. Literature search

We searched the ISI Web of Knowledge (http://www.isiknowledge.com) for papers with the terms "map", OR "spatial distribution", OR "spatial pattern", AND that also included one or more of the following terms "ecosystem services", OR "ecosystem goods and services", OR "ecological services". All databases in ISI Web of Knowledge were used for this search, which yielded 605 studies (as per May 12, 2012). Based upon this search we selected only studies that (i) were performed within an ecosystem service framework, (ii) had a connection to a case study, thus excluding conceptual papers, (iii) included more than one service, (iv) were conducted in terrestrial, and not marine systems, and (v) presented spatially explicit quantification of ecosystem services on a smaller scale than global. Thirty-nine papers met these criteria (Appendix A).

The largest portion of the papers was omitted because of the lack of a case study, i.e. papers which were discussing the topic of ecosystem services, and the importance of mapping and monitoring ecosystem services and their spatial distribution, while not actually carrying out a mapping study. Furthermore, as the interest of this review was to analyse mapping studies involving multiple ecosystem services, many papers were omitted because of the mapping of a single service only. This search method resulted in a relatively small amount of studies compared with other more comprehensive review papers (Martínez-Harms and Balvanera, 2012; Egoh et al., 2012; Crossman et al., 2013). The reason for this is most likely the choices of database. This review uses the ISI Web of knowledge only, while the other reviews use more than one database.

One of the papers mapped services at four different spatial scales and one paper at two different scales. One paper included four separate case study areas in three different countries. One paper carried out national scale mapping studies in two adjacent countries. Each study scale *and/or* study area of those four papers was treated as a separate study in this analysis; hence the number of studies from the 39 papers was 47. In total, 300 unique ecosystem services entries, henceforth called ES entries, were mapped across the 47 studies, named and categorized according to the typology presented in Table 1.

2.2. Defining scale

For this paper we defined the scale of a study in two different ways: the grain (i.e. resolution) and the extent (i.e. total area mapped). In a few of the selected papers, it was not clear what resolution was used. The resolution (grain size) was divided into four categories: $<0.01\ km^2$, $0.01\ km^2$, $1–5\ km^2$ and $100\ km^2$. There were no studies with a resolution of $>100\ km^2$, and no studies with a resolution between 0.01 and $1\ km^2$. We grouped total extent of the study area into five scale levels: village/farm, municipality, province, nation and continent (see Table 2 for scale definitions).

2.3. Typology

In the literature search, we found a wide range of typologies and definitions of ecosystem services. To enable analysis, we re-named and categorized the services included in the reviewed papers. We modified the MA framework (MA, 2005) to include parts of The Economics of Ecosystems and Biodiversity (TEEB) typology (TEEB, 2010) to better match the services used in the papers (Table 1). In total, 22 different services were categorized within the four categories, i.e. provisioning, regulating, cultural and supporting/habitat services (Table 1).

We also included biodiversity in the typology to reflect the fact that biodiversity was often treated as an ecosystem service in the reviewed papers. There is an ongoing debate on whether biodiversity is an ecosystem service or should be viewed outside of the ecosystem services framework underpinning all other services (Mace et al., 2012; Reyers at el., 2012). Thus, the placement of biodiversity in the typology was not straight forward. In some of the reviewed papers, biodiversity was reflecting diverse or rare species or habitats, or considered as enriching the experience of it, and can be seen as a cultural service. In other papers, biodiversity was treated as genetic, functional or habitat diversity for future options (Sensu Noss, 1990). To enable separate analysis of cultural services, we categorized biodiversity either as a Cultural service or as a Supporting/habitat service, depending on what parameters and indicators were used in the original papers (Table 1).

Separating the processes underpinning water regulation as a regulating service and the production of freshwater as a provisioning service is difficult, therefore we include all water quantity related services and proxies in the service Water quantity regulation, placed in the category regulating services (Table 1). Note that the services are re-named and grouped according to the parameters or proxies that were mapped and not what they were called in the papers, thus water quantity regulation and water quality regulation both contain "Freshwater".