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Mapping of ecosystem services: Missing links between purposes and procedures

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ABSTRACT

The literature on ecosystem services mapping presents a diversity of procedures whose consistency might question the reliability of maps for decision-making. This study aims at analyzing the correspondence between the purpose of maps (e.g. land use planning) and the procedures used for mapping (e.g. benefit transfer, ecological transfer). Fifty scientific studies published between 2005 and 2012 were selected and analyzed according to 19 variables, applying independence tests over contingency tables, ANOVA and regression analysis. The results show that most studies declared a decision-making purpose (82%), which in 50% of the cases, was land use planning. Only few relationships were found between variables selected to describe the purpose of the maps and those selected to describe the mapping procedures. Thus for example, maps aimed at supporting land use planning did not include any level of stakeholder participation or scenario analysis, as it would have been expected given this purpose. Likewise, maps were based on either economic value or biophysical transfers, regardless of the spatial and temporal scales of mapping. This generally weak relation between map's purposes with the used procedures could explain the still restricted incidence of ES on decision-making by limiting the transmission, comparison and synthesis of results.

1. Introduction

Explicit mapping of ecosystem services (henceforth ES) is recognized as a key step for the implementation of the ecosystem services framework in decision-making (Daily and Matson, 2008; Daily et al., 2009; Burkhard et al., 2011; Seppelt et al., 2011; Hauck et al., 2013; Villamagna et al., 2013). In recent years a range of procedures have been proposed for ES mapping (see for instance, Troy and Wilson, 2006; Egoh et al., 2008; Naidoo et al., 2008; Willemen et al., 2008; Nelson et al., 2009; Tallis and Polasky, 2009; Seppelt et al., 2011; Crossman et al., 2013). Nelson et al. (2009) categorized these procedures under three general types. The first category consists of broad-scale assessments of multiple ES used to extrapolate a reduced number of value estimates, based on habitat types, regions, or the planet (see examples in Costanza et al., 1997; Troy and Wilson, 2006; Viglizzo and Frank, 2006; Turner et al., 2007). While simple, this transference of benefits has two restrictions: (i) it is based on the simplified assumption that every hectare of a given habitat type is of equal value – regardless of its quality, rarity, size, spatial configuration, neighboring land uses, proximity to ES beneficiaries and population centers, or the prevailing social practices and values; and (ii) it does not allow for analyses of service provision and changes in value under new scenarios.

The second type consists in modeling the provision of a single or few services in a small area using mechanistic models of ecosystem processes or fitting empirical responses to ecosystem variables ("ecological production functions") (see examples in Kaiser and Roumasset, 2002; Ricketts et al., 2004) that relate

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ES fluxes with local ecological variables. While this approach probably brings more reliable results than benefit transfer, it is generally restricted to provisioning services and tends to lack both the scope (number of services) and scale (geographic and temporal) for most policy matters (Nelson et al., 2009 and references therein). Finally, the third and most recent type is the social mapping of ES which emphasizes social perceptions, values and priorities over economic and ecological indicators. These methods commonly incorporate informants who are given a preliminary list of ES and then asked to associate values with landscape areas. An important issue that emerges from social mapping is the potential effect of "super-mappers" (*sensu* Ambrose-Oji and Pagella, 2012) since "when no limits are placed on the number of ES "markers" that can be placed on maps, some participants tend to place many more markers than others" (Ambrose-Oji and Pagella, 2012). This has noticeable implications in terms of the representativeness of the maps produced using these techniques. Examples of social mapping can be found in Raymond et al. (2009), Sherrouse et al. (2011), Fagerholm et al. (2012), and Plieninger et al. (2013).

Despite the important progresses in the development of mapping procedures, studies published in the last years (see for example, Seppelt et al., 2011; Martínez-Harms and Balvanera, 2012; Hauck et al., 2013; Crossman et al., 2013; Nahuelhual et al., 2013a) comment on the lack of consistency and adequacy between procedures and assessment purposes, which might question the reliability of maps for decision-making. For example, benefit transfer as an economic technique is applied for biodiversity conservation, for the design of payments for ecosystem services (PES) and for land use planning alike. In turn, land use planning is assumed to be equally supported by ecological assessments of functions and services, benefit transfer, social value mapping or mixed techniques (Nahuelhual et al., 2013a). The weak relation between a map's purpose and the attributes of the procedures used, could explain in part the still limited incidence of ES spatial assessment on decision-making (Villamagna et al., 2013).

In this context, the objective of this work was to analyze the correspondence between the purpose of maps (e.g. land use planning) and the procedures used for mapping (e.g. benefit transfer, ecological transfer), through a review of selected published studies that spatially assessed ES. The manuscript expects to contribute to the ES mapping literature by pointing at the main issues behind the insufficient consistency of mapping techniques, which still limits the transfer, comparison and synthesis of mapping results at different scales.

2. Methods

2.1. Search of scientific studies

Given the purpose of the study, the following search profile was applied to titles, keywords and abstracts: ("*ecosystem functions*" OR "*ecosystem service*" OR "*landscape service*" OR "*environmental service*" OR "*ecosystem good*" OR "*ecosystem benefit*" OR "*ecosystem services vulnerability*") AND ("*mapping*" OR "*map*" OR "*land use change*"). The selected material included original articles and key monographs obtained from SCOPUS database, published in English. The selection was narrowed to terrestrial ecosystems excluding seascapes. In this way, 99 studies published between 2000 (date of the first article retrieved by the search profile) and 2012 were preliminary selected. The final collection of studies for the analysis was obtained based on two criteria. The first one was directed to avoid the influence of earliest and mostly exploratory studies. Therefore, 2005 was chosen as the starting year for the following reasons. From this year on, there was an exponential growth in published studies on ES mapping (Martínez-Harms and Balvanera, 2012) and significant contributions were released which prompted the development and use of mapping procedures, such as for example "*The Economics of Ecosystems and Biodiversity*" (TEEB, 2010) and the "*Partnership for European Environmental Research*" (PEER) Report (Maes et al., 2011). Additionally, after 2005 specific software were developed and released such as Integrated Valuation of Environmental Services and Tradeoffs (InVEST) (Nelson et al., 2009; Tallis and Polasky, 2009), *Social Values for Ecosystem Services* (SolVES) (Sherrouse and Semmens, 2012) and Artificial Intelligence for Ecosystem Services (ARIES) (Villa et al., 2009). In this way, studies published between 2005 and 2012 captured 95% of the total studies retrieved between 2000 and 2012, while probably filtering too early mapping procedures. The second selection criterion was the development in the research article of at least one map (showed or only declared) of an ecosystem function, ecosystem service or benefit, in order to rule out papers that mapped other landscape features (e.g. land cover map; biodiversity map). Over this preliminary filtering, a random selection was conducted to finally choose 50 studies, which came from international indexed journals and international organization's key reports (i.e. UNEP). The sources comprised several aspects of ecology, environmental science and other natural sciences, as well as environmental modeling, economy and environmental policy.

2.2. Analysis of the selected studies and data base construction

The analysis of the studies was conducted around the following criteria: (i) the correspondence between a map's purpose and used procedures; (ii) the consistency among methodological variables of each procedure; and (iii) the relationships of mapping purposes and procedures with map quality. To achieve this, 19 variables were selected to characterize purpose, methodological procedures, and quality of maps, as detailed in Table 1. These 19 variables were created and agreed upon by the authors as those that best represented these three criteria.

The purpose of maps was characterized according to the author's statement of specific mapping objective/s, the type of decision the study declares to support, the geographic or political scale of mapping, and the existence or not of a recognized private or public stakeholder need. Consistency of procedures was understood as the existence of association patterns between different methodological variables (in contrast to their independent adoption). Quality of ES maps as a confidence tool for decision-making, was represented by two variables: (i) the "distance" between what is mapped and what is needed for informed decision-making (*distance to decision making*, Table 1), and (ii) the integrality of the mapping approach, which was understood as the level of adoption of a sequence of logical procedures, capable of connecting the ecosystem biophysical properties with capture and valuation of the consequent benefits (*cascade integration*, Table 1). This logical sequence implies mapping the different elements suggested by the ecosystem services framework as presented by Turner and Daily (2008) and backed up by "*The Economics of Ecosystems and Biodiversity*" (TEEB, 2010) and synthesized in the "*services cascade*" model (*sensu* Haines-Young and Potschin, 2010).

A data base was created where each row was one of the 50 selected study and the columns were the 19 variables described in Table 1. Relations among variables were explored using different types of univariate analysis according to variable types. Associations among categorical variables belonging to the same group or among groups of variables, were analyzed by the Fisher Exact Test on contingency tables. Relations among categorical vs. continuous (*mapped area*) or discrete (*number of components mapped*, *number of ES mapped*) variables were tested by comparing continuous or discrete variables among categories using ANOVA. Finally,