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Editorial: Best practices for mapping ecosystem services

1. Introduction

Plurality in ecosystem service definitions and applications has resulted in a wide variety of methods to assess and map ecosystem services (ES). Although this helped the field to progress and evolve in several directions and contexts, this diversity challenges the mainstreaming of ES information into policy making, natural resource management and green accounting. The Mapping[2] and Modelling[3] working groups of the Ecosystem Service Partnership (ESP) have taken up the challenge to provide structure and guidance in ES mapping practices. The ESP working groups have developed a checklist of information and decisions needed for ES mapping and documentation (Crossman et al., 2013), an online data sharing platform for ES maps (http://esp-mapping.net), and a series of Special Issues (SI) on ES mapping in scientific journals (Crossman et al., 2012, Burkhard et al., 2013, Alkemade et al., 2014). In our search for best ES mapping practices to support decision making we, as leads of the related ESP working groups, invited papers for this SI with recommendations on the ES mapping methods and a description of their applicability under specific geographic characteristics and user objectives. Decision-making in which ES maps can play a role is not restricted to national governments, but involves, for example, private companies, watershed managers and non-government organizations. Based on the collection of papers in this SI, we found that the best ES mapping practices to support decision making should be *robust*, *transparent* and *stakeholder-relevant*. These mapping practices include robust modeling, measurement, and stakeholder-based methods for quantification of ES supply, demand and/or flow, as well as measures of uncertainty and heterogeneity across spatial and temporal scales and resolution. Best ES mapping practices are also transparent to contribute to clear information-sharing and the creation of linkages with decision support processes. Lastly, best ES mapping practices are people-central, in which stakeholders are engaged at different stages of the mapping process and match the expectations and needs of end-users.

Based on the 16 papers included in this SI, this editorial provides an overview of the best practices and remaining challenges, that lead to robust, transparent and stakeholder-relevant ES mapping for supporting diverse decision-making in diverse contexts.

2. Robust ecosystem services mapping practices

A large number of papers in this SI aimed to improve technical aspects of mapping approaches. Law et al. (2015) demonstrate that the choice of measure for carbon stocks and emissions results in different spatial patterns, which has strong implications for carbon management and land use policies such as REDD+. Careful consideration of ES metrics by researchers is therefore critical to ensure their effective and efficient use by policy-makers. Grêt-Regamey et al. (2015) propose a four step tiered ES mapping approach for selection of variables to describe multi-level systems. To address the spatial connectivity between ecosystems and their beneficiaries, Vrebos et al. (2015) show how quantifying flow directions of ecosystem services can improve ES maps and assessments. Pert et al. (2015) show that variations in social attributes (e.g. cultural customs), rather than the ecological attributes (e.g. biodiversity patterns), primarily determine the spatial variation in cultural ES. Their finding highlights the importance of considering a wide range of variables for mapping ES.

Besides choices for thematic ES mapping variables and metrics, choices of data attributes impact mapping practices. Malinga et al. (2015) reviewed 47 ES mapping studies to explore if data-resolution was potentially impacting decision-making on land-sparing or land-sharing. Their review shows that most studies were conducted at a fine spatial resolution capturing different functions of heterogeneous landscapes, which could therefore guide both land sparing and land sharing policies. The type of input and output data of spatially explicit ES quantification methods impacts map accuracy which has consequences for decision making. Schröter et al. (2015) explore the relation between accuracy and feasibility of 29 different spatial ES models for ecosystem accounting (EA) purposes. Aiming for high accuracy will challenge the feasibility of the study. The authors list six constraints impacting feasibility which researchers should consider in relation to their spatial model choice and modelling objective. These constrains are: (i) spatial scale of the study area, (ii) heterogeneity of the area, (iii) budget and available time, (iv) knowledge, experience and affinity with the study area, (v) societal relevance of the ES, and (vi) accessibility of the study area.

Many studies in this SI discuss data challenges and limitations. Robust mapping methods can be considered as those that are the strongest methods in the face of data limitations. A number of studies in this SI present a clever integration of different data sources to best achieve their mapping objectives. Van Oort et al. (2015) use multiple approaches to integrate complementary information and to verify information across methods. In this study local perceptions of ecosystem use, change and values were obtained using participatory tools, and cross-validated with

[2] http://www.es-partnership.org/esp/79222/5/0/50.
[3] http://www.es-partnership.org/esp/79026/5/0/50.

http://dx.doi.org/10.1016/j.ecoser.2015.05.008

scientific literature, statistics and remote sensing data. The authors recommend linking methods and related data of different spatial levels leading to complementary types of insights and detail needed for balanced and informed decision-making. Paudyal et al. (2015) also present mapping practices based on participatory methods (interviews and focus group discussions) integrated with freely accessible satellite images and repeat photography. Ramirez-Gomez et al. (2015) recommend participatory GIS (PGIS) approaches for areas lacking adequate spatial-temporal data to map trends in ES stocks and supply locations. Fast and efficient methods were explored in spatial data-poor environments, such as digital photo-questionnaires to specify landscape aesthetics for mapping recreation demand (Peña et al., 2015) and integration participatory and expert knowledge on the capacities of different land use and land cover types to supply different ES (Sohel et al., 2015).

2.1. Challenges towards robust ecosystem services mapping practices

Contributors to this SI critically reflect on current advances of robust ES mapping practices. Regarding data selection, a note was made about the selection of ES measures, i.e. 'proxies', to support decision making. Law et al. (2015) state that one might also need to consider the 'incentive value' of ES proxies in addition to the measurement and surrogacy values. A proxy with a low incentive value is, for example, a proxy of process that one has little control over or poorly communicates the ES, which therefore has a reduced value for decision making.

Many SI contributors suggest that current research insufficiently assess and communicates the accuracy of ES maps, as also shown in earlier reviews (Eigenbrod et al., 2010a, 2010b). ES maps rarely report on accuracy, uncertainties, nor on reliability in relation to a decision-making application. Related to this, studies using data obtained through participatory approaches lack assessment of the correspondence between people's perceptions and actual use of ecosystem goods and services (Paudyal et al., 2015). Participatory methods do not automatically meet 'scientific' requirements for technical accuracy and statistical estimation (Ramirez-Gomez et al., 2015). Therefore these authors argue that data obtained through participatory approaches best serve to exploratory and hypothesis-generating stages of science-based projects. Brown and Fagerholm (2015) reviewed 30 papers on Public Participation and Participatory GIS (PPGIS and PGIS) to synthesize the advances of PPGIS/PGIS practices related (i) data quality, (ii) decision support, and (iii) feasibility. They concluded that there are no objective standards or benchmarks to assess the positional accuracy and completeness of mapped PPGIS/PGIS data.

According to SI contributors, the 'generalizability' of ES mapping approaches is a challenge to the quest for robust approaches. This challenge was particularly mentioned by authors incorporating stakeholder perceptions and values in their mapping approaches. While generalizability of ES mapping approaches has a spatial element (i.e. application to different locations at various spatial scales), it also has a temporal element (i.e. application of approaches after changes in demand, awareness or dependence on a specific ecosystem service) (Van Oort et al., 2015). Based on their review of ES mapping studies, Malinga et al. (2015) conclude that ES mapping methods should include more systematic cross-site and cross-scale comparisons to support management practices for multiple spatially interacting services.

We are especially concerned about the lack of validation and accuracy assessments of ES maps. Remote sensing-based land cover maps standardly report the accuracy rate of different land cover type classifications. The mapping complexity of (sometimes intangible) ES is much greater than remote sensing land cover mapping because multiple data sources are combined to assess ES supply, demand or flows. This makes map validation more complex but also strongly needed. We firmly suggest that 'Best ES Mapping Practices' include estimates of accuracy. We could imagine ES maps that indicate 'hotspots of certainty'.

3. Transparent ecosystem services mapping practices

Almost all maps present outputs from models, which (like the maps themselves) are simplifications of reality. Best mapping practices need to be explicit in describing model assumptions, underlying data and model approaches, and should state the purpose of map creation. This should minimize inadequate use or misinterpretation of ES maps. Drakou et al. (2015) present the Ecosystem Services Partnership Visualization Tool (ESP-VT; http://esp-mapping.net/), an open-access interactive platform that provides a systematic organization, visualization and sharing of ES maps and related information. The tool aims to increase transparency in ES mapping approaches, to facilitate the flow of information within the ES community, and between researchers, policy-makers and practitioners. A range of ES maps presented in the SI together with their linked information are available online through ESP-mapping.net.

3.1. Challenges towards transparent ecosystem services mapping practices

Transparent and exchangeable ES mapping approaches are challenged by the lack of consistent ES nomenclature which serves as a basis to formulate data standards for ES maps and relevant information (Drakou et al., 2015). Brown and Fagerholm (2015) conclude in their review of PPGIS/PGIS approaches that mapping of ecosystem services would benefit from experimental design and research controls allowing for the systematic comparison of outcomes using alternative operational definitions, mapping approaches at different map scales and with different sampling designs. Their review demonstrated that there is currently little comparability across case studies that are socially and geographically context-dependent.

4. Stakeholder-relevant ecosystem services mapping practices

Best ES mapping practices meet the expectations and needs of map users and engage with stakeholders at different stages of the mapping process to best capture what ES are all about: the link between ecosystems and people. To identify and prioritize relevant stakeholders, Brown and Fagerholm (2015) recommend using stakeholder analyses to incorporate multiple societal interests and values in participatory mapping of ecosystem services. For example, García-Nieto et al. (2015) recommend including the different spatial perceptions of ES that stakeholder groups have, which is shown with the explicit inclusion in their PPGIS assessment of 'low and high influence stakeholders'. Darvill and Lindo (2015) further emphasize the inclusion of stakeholders who have diverse uses of ES (economic and non-economic) in the ES mapping practices.

To meet the expectations and needs of map users, Nahuelhual et al. (2015) list location characteristics to help researchers to select ES mapping methods which correspond with ES mapping purposes. In their extensive review of decision-maker needs, Klein et al. (2015) highlight that ES information can be presented in diverse ways depending on the expected use of the information. Besides thematic 2D maps (the typical spatial representation of ES), authors recommended considering using 3D landscape representations, texts, abstract 3D visualizations, and charts and tables combined with 2D maps.