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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
2212-0416/

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.

Table 1
Recommendations for Best ES mapping practices given in this SI*.

Best ES mapping practices are	For example by	Read about this in	Which is a case study/example	
			For	At this spatial level
Robust	Using fine grain input data to capture multiple functions of an area in maps.	Malinga et al. (2015)	ES quantification	(Review)
	Evaluating the impact of your ES metric selection.	Law et al. (2015)	ES quantification	Sub-national
	Using a tiered approach for ES mapping to select the adequate combination of variables in multilevel systems.	Grêt-Regamey et al. (2015)	ES quantification	Continental, country, municipality
	Understanding how accuracy and modelling feasibility relate to each other when selecting a spatial ES model.	Schröter et al. (2015)	ES accounting	NA
	Using PGIS to visualize past and present trends of Service Providing Areas in spatial/temporal data-poor areas.	Ramirez-Gomez et al. (2015)	Prioritization of intervention areas	Sub-national
	Using participatory tools, integrated with free access satellite images and repeated photography, in spatial-data poor regions.	Paudyal et al. (2015)	ES quantification	Sub-national
	Using digital photo-questionnaires to specify landscape aesthetics for mapping recreation demand, as a fast and efficient approach, resulting in high response rates.	Peña et al. (2015)	Prioritization of intervention areas	Sub-national
	Using participatory and expert knowledge for gaining quick overviews about land use/land cover types' capacities to supply different ES, especially in data-poor regions.	Sohel et al. (2015)	ES assessment	Sub-national
	Capturing variations in social attributes, rather than the ecological attributes to describe spatial patterns of cultural ecosystem services.	Pert et al. (2015)	ES quantification/ rates	Sub-national
	Using multiple mapping approaches for integration of complementary information and/or for verification of information across methods.	Van Oort et al. (2015)	ES quantification, ES valuation	Sub-national
	Integrating flow directions into ecosystem services scoring maps and assessments to include the spatial connectivity between ecosystems and their beneficiaries.	Vrebos et al. (2015)	Scenario impact assessment	Sub-national
Transparent,	Using ecosystem service data that are spatially explicit with clear operational definitions for mapped attributes.	Brown and Fagerholm (2015)	(Review)	(Review)
	Providing some degree of standardization and commensurability across services.	Brown and Fagerholm (2015)	(Review)	(Review)
	Systematically include details on ES metrics, mapping objectives and underlying data and methods to support interpretation and adequate use of ES maps.	Drakou et al. (2015)	General decision making support, peer-learning scientists	NA
	Online sharing of maps in GIS format.	Drakou et al. (2015)	General decision making support, peer-learning	NA
Stakeholder-relevant	Including a wide range of ecosystem services, for different beneficiary groups.	Brown and Fagerholm (2015)	General spatial planning	(Review)
	Considering different spatial perceptions of ES across stakeholder groups in decision making processes (i.e. among *low* and *high influence stakeholders*).	García-Nieto et al. (2015)	ES quantification (supply & demand)	Sub-national
	Addressing diverse stakeholder ES uses (economic & non-economic).	Darvill and Lindo (2015)	ES quantification	Sub-national
	Presenting information on ES in diverse ways depending on the objective: thematic 2D maps, 3D landscape representations, Texts, Abstract 3D visualizations, and Charts and tables combined with 2D maps.	Klein et al. (2015)	General decision making support	(Review)
	Selecting the ES mapping method that corresponds to the ES map purpose.	Nahuelhual et al. (2015)	(Review)	(Review)
	Involving stakeholders in ES mapping.	Darvill and Lindo (2015), García-Nieto et al. (2015), Paudyal et al. (2015), Peña et al. (2015), Pert et al. (2015), Ramirez-Gomez et al. (2015), Van Oort et al. (2015), and Vrebos et al. (2015)		Sub-national

NA: not applicable.

* Some recommendations might contribute to more than one aspect of best mapping practices, but these are only listed once. The contribution of Sohel et al. has been published in a previous issue of *Ecosystem Services*.

A large number of contributions to the SI have used approaches that involve stakeholders in mapping ES. This is giving us the impression that for many ES mapping is a true interdisciplinary effort involving the integration of information on the social and biophysical systems.

4.1. *Challenges towards stakeholder-relevant ecosystem services mapping practices*

Despite the efforts to make ES mapping studies stakeholder-relevant, Brown and Fagerholm (2015) concluded from their

PPGIS/PGIS mapping review that none of their reviewed studies report the use of mapped ES in decision-making. They argue that PPGIS/PGIS ES mapping is a process that is driven largely by researchers, and has primarily focused on producing rational, scientifically defensible results, rather than focusing on use in decision-making. They highlight the challenge of time mismatches between scientific projects and temporal scales of decision-making.

While there is consensus that ES mapping methods should be fit for purpose, Nahuelhual et al. (2015) found a lack of correspondence between purposes and general mapping procedure. This suggests that similar techniques were applied to diverse purposes and, reciprocally, the same problem was analysed using different mapping techniques. It seems that the selection of ES mapping methods is often not based on ES purpose, but driven by other factors.

Pert et al. (2015) mention literacy and language barriers in their attempt to implement stakeholder-relevant mapping practices. The indigenous people they worked with lacked access to basic school education and scientific knowledge, while most non-indigenous participants lacked access to indigenous knowledge and world views, particularly the spiritual aspects, an important element of their cultural ES.

5. 'Best Practices' of mapping ecosystem services to support decision making

Examples of maps that were created within the ES paradigm (i.e. Labelled as such) that have been used to support better decision making are still rare (Brown and Fagerholm, 2015; Nahuelhual et al., 2015). Even though not many clear success stories on the use of ES maps in decision making are available, the rich experience of ES mappers still allows us to identify many recommendations for best ES mapping practices. In Table 1 we summarize all ES mapping practices recommended by contributors of this SI by purpose and spatial level. The ES mapping purposes include the support of decision making and spatial planning related to: (i) ES valuation; (ii) ES quantification; (iii) ES congruence; (iv) ES trade-offs; (v) scenario impact assessment; (vi) prioritization of intervention areas; and (vii) ES cost-benefit analyses and accounting (Egoh et al., 2012).

In this SI we aim to identify ES mapping practices resulting in maps that could best support decision-making. However, many contributors explicitly mention another outcome of a mapping practice besides a map: ES awareness-raising. Many of the presented ES mapping approaches are not only output oriented, but also process oriented. The social outcomes of ES mapping processes, such as social learning and the creation of social capital, are important drivers of sustainable land use (Brown and Fagerholm, 2015). Also, the resulting ES maps can serve a purpose to indirectly affect decision-making such as initiating discussions about the relevance of ES and biodiversity (Nahuelhual et al., 2015). Other social outcomes that contributors to this SI listed as an important contribution towards sustainable future land use are: (i) awareness-raising and community engagement (Paudyal et al., 2015); (ii) empowerment effects (Ramirez-Gomez et al., 2015), and; (iii) the transfer of ecological knowledge within (and among) the communities and across generations (Ramirez-Gomez et al., 2015). Despite the great importance of these social processes, little attention has been devoted to assessing the achievement of these social objectives in ES mapping practices (Brown and Fagerholm, 2015).

To conclude our synthesis of papers in this SI on Best Practices for ES Mapping we found that standardized measures and mapping methods are expected to increase methodological robustness, information-sharing and decision-making impact, whereas a plurality of approaches is needed to address different user needs, objectives and data availability in different contexts. Although this suggests a paradox, a solution may be for ES mapping practices to fully embrace a fluid exchange of methods, data and knowledge to increase transparency and acceptance for better decision-making. Multiple and flexible approaches of ES mapping are needed to gain acceptance within society while at the same time being stakeholder-relevant (Brown and Fagerholm, 2015).

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Louise Willemen [1]
Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Hengelosestraat 99, 7514 AE Enschede, The Netherlands
Department of Natural Resources, Cornell University, Ithaca NY 14853, USA

Benjamin Burkhard
Kiel University, Institute for Natural Resource Conservation, Olshausenstr. 40, 24098 Kiel, Germany
Leibniz Centre for Agricultural Landscape Research ZALF, Eberswalder Street 84, 15374 Müncheberg, Germany

Neville Crossman
CSIRO Land and Water Flagship, PMB 2, Glen Osmond, SA 5064, Australia

Evangelia G. Drakou
Université de Brest, UMR M101, AMURE, OSU-IUEM, 12 rue du Kergoat CS 93837, F-29238 Brest Cedex 3, France

Ignacio Palomo
Basque Centre for Climate Change (BC3), Alameda de Urquijo 4, 48008, Bilbao, Spain
Social-Ecological Systems Lab, Universidad Autónoma de Madrid, Darwin 2, 280049 Madrid, Spain

[1] Managing Guest Editor