Practical solutions for bottlenecks in ecosystem services mapping

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Abstract

Background

Ecosystem services (ES) mapping is becoming mainstream in many sustainability assessments, but its impact on real world decision-making is still limited. Robustness, end-user relevance and transparency have been identified as key attributes needed for effective ES mapping. However, these requirements are not always met due to multiple challenges, referred to here as *bottlenecks*, that scientists, practitioners, policy makers and users from other public and private sectors encounter along the mapping process.

New information

A selection of commonly encountered ES mapping bottlenecks that relate to seven themes: i) map-maker map-user interaction; ii) nomenclature and ontologies; iii) skills and background; iv) data and maps availability; v) methods-selection; vi) technical difficulties; and vii) over-simplification of mapping process/output. The authors synthesise the variety of solutions already applied by map-makers and map-users to mitigate or cope with these bottlenecks and discuss the emerging trade-offs amongst different solutions. Tackling the bottlenecks described here is a crucial first step towards more effective ES mapping, which can in turn ensure the adequate impact of ES mapping in decision-making.

Keywords

Ecosystem services, mapping, solutions, spatial analysis, sustainability.

Introduction

Mapping has become one of the most prolific fields within ecosystem service (ES) science (Crossman et al. 2013;Klein et al. 2016). Robustness, end-user relevance and transparency have been identified as key requirements of ES maps (Willemen et al. 2015b). However, ES maps and mapping processes often fall short in meeting these requirements, limiting the impact of ES science (Root-Bernstein and Jaksic 2017). ES mapping is a complex process that presents several challenges ranging from data availability aspects to integration of mapping outputs in decision-making (Burkhard and Maes 2017). These challenges, referred to here as bottlenecks, need to be solved to leverage the impact of ES mapping and in consequence, the implementation of the ES science in decision-making as a whole.

ES mapping has received much attention because it provides a clear link between ES and spatial planning (Albert et al. 2016). This attention in research and practice is expected to increase, given, for example, the explicit demand from the EU Biodiversity Strategy to Member States to evaluate and map ES (Target 2 - Action 5) (Maes et al. 2016) and the upcoming environmental accounting (e.g. SEEA EEA). Given the increased importance of ES mapping, the aim of this paper is to present the most widespread ES mapping challenges and potential solutions. Specific objectives are: (i) to provide an overview of the most widespread bottlenecks in ES mapping; and (ii) to point to possible solutions for map-makers and map-users that have been successfully implemented. This can help ES mappers and map-users to find ways around challenges and to improve the utility of ES maps for sustainable decision-making.

Materials and Methods

Methods

This paper is based on the results of 19 semi-structured questionnaires and the work presented in the thematic session on mapping ES "Solving practical bottlenecks in ecosystem service mapping" that took place during the European Ecosystem Services Partnership (ESP) Conference in Antwerp in 2016. During the thematic session, presenters were asked to discuss their challenges and solutions during the ES mapping processes in which they had participated before and a broad range of ES mapping bottlenecks and practical solutions were covered. After the conference, which included 12 presentations, a semi-structured questionnaire was designed and distributed to the session participants and other ecosystem service mappers and maps-users to collect information on mapping bottlenecks and potential solutions. The questionnaire had three main sections: i) Mapping purpose; ii) Description of the bottleneck faced; iii) How the bottleneck was solved.

Results

The questionnaire results included bottlenecks faced during ES mapping exercises covering all ecosystem service categories, and multiple spatial scales from local to national, continental and global. Bottlenecks can be encountered in different phases of the mapping process, which we describe here as a circular process in which the tangible outcomes (maps) need to be evaluated and discussed to help to define shared objectives. The landscape planning cycle presents a powerful way to illustrate the mapping process and the ES mapping bottlenecks that are encountered along the different phases (Fig. 1). As illustrated for watershed planning, some bottlenecks exist during the whole planning process such as those referred to knowledge co-production or knowledge transfer as Bottleneck 1: Map-maker map-user communication, whereas others such as Bottleneck 6: Technical difficulties, emerge predominantly through the implementation phase Adem Esmail and Geneletti 2017. The seven challenges identified are presented with different potential solutions for map-makers and map-users in Table 1. The presented bottlenecks and solutions have been identified by scientists and practitioners within the Ecosystem Services Partnership (ESP) network (https://www.es-partnership.org).

Bottleneck 1. Map-maker map-user communication

Refers to cases where the mapped outputs produced do not meet the end user needs because of poor communication between the map-maker and the map-user. This can occur when the end user's data requirements and decision-making process are not fully understood by the map-maker. It is also related to communicating uncertainty and to transferring the message accurately in a way that is relevant but understandable for end users.

Science-policy iterative processes and capacity building have been suggested as means to improve map-maker to map-user communication and to solve the ES implementation gap (Ruckelshaus et al. 2015). This could be achieved through continuous and more intense collaboration of researchers with decision-makers and involving decision-makers through the mapping process (e.g. through Participatory Geographic Information Systems (PGIS) and validation of outputs). Since the final map is the main communication output - and thus the decision-making base, the map-maker should never underestimate the importance of the basic principles of map design, metadata, documentation of the methodologies, explanation on the interpretation of the map as well as stating their limitations (Burkhard and Maes 2017). At the same time, dedicated efforts to capture user needs, using methods such as usability analysis (Gotz and Zhou 2009) should be adopted as an inherent part of the ES mapping process. Higher transparency and better explanation of the (meta)data and methods used to map ES can also enhance map-maker to map-user communication (Crossman et al. 2013). For a review about knowledge integration and social learning that takes place through the shared use of Spatial Decision Support Systems (SDSS), see Rodela et al. (2017).

Researchers have attempted to solve communication bottlenecks through communities of practice and sharing platforms for ES such as the ESP Visualisation tool (Drakou et al. 2015) (http://esp-mapping.net/Home/), the ECOPLAN Monitor (http://www.ecosysteemdiensten.be) and OPPLA (http://www.oppla.eu/). Yet, it is necessary to assess whether these platforms fulfil users' needs and how these platforms can be harmonised, maintained and improved. The way ES are visualised also contributes to map-maker and map-user communication. In some cases, 3D maps and infographics combining maps, tables and text cover better the needs of map users (Klein et al. 2015). Moreover, adopting metadata standards (i.e. the INSPIRE Directive 2007/2/EC) can facilitate communication amongst those involved in the map-making process.

Bottleneck 2. Nomenclatures and ontologies

Refers to mapping barriers encountered due to differences in the use and understanding of ES classifications and terminology (such as the Common International Classification for Ecosystem Services (CICES), The Millennium Ecosystem Assessment (MEA), The Economics of Ecosystems and Biodiversity (TEEB), The Final Ecosystem Good and Services Clasification (FEGS), or the classification from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)).This also includes the trade-off between the standardisation or interoperability of ES classifications and context adequacy, as ES can have different meanings depending on the framework used for conceptualising them (e.g. ES potential vs. supply vs. flow vs. demand; intermediate vs. final ES; different human-nature worldviews) and the mapping contexts (e.g. spatial scale of assessment). This bottleneck also refers to challenges that arise when ES classifications hinder the expression of ES values that stakeholders hold (Fagerholm et al. 2016) and to the fact that different understandings of ES concepts amongst stakeholders (Lamarque et al. 2011) and professionals (Kulczyk et al. 2014) deliver different ES evaluations. Some nomenclature challenges also emerge when ES maps are needed at both broad and local scales, making comparability difficult.

Using ES free-listing (bottom-up classifications), flexible classification systems and pre-testing classifications with diverse stakeholders across scales have been widely applied to overcome these difficulties (Martín-López et al. 2012,Willemen et al. 2017). The use of more diffuse ES classification, such as that of Nature Contributions to People (NCP) from IPBES, in contrast with other siloed classifications (e.g. MEA, The Economics of Ecosystems and Biodiversity (TEEB), CICES), can enhance our understanding of ES complexity (Pascual et al. 2017). Guidelines or tables to crosswalk amongst classifications can also be useful for map users to deal with co-existing classification systems (Haines-Young and Potschin 2014). Platforms for ES mapping based on ontologies such as ARIES (Villa et al. 2014) are useful for avoiding this challenge since new ontologies adapted to specific contexts can be developed.

A combination of existing and emerging classifications has been applied as well. Campagne et al. (2017) faced the nomenclature bottleneck when trying to apply the CICES (Haines-Young and Potschin 2012) on the ground. Provisioning and regulating services' classification, definitions and examples were adapted to local contexts by map-makers and map-users and a new classification for cultural ES was specifically developed because the CICES was perceived as too abstract for local stakeholders.

Stronger and more detailed socio-cultural assessments that connect the state of biodiversity with human well-being to elicit stakeholders´ values are still needed to facilitate the adequate understanding of multiple value types. Several ontological concepts such as the SERONTO ontology (Werf B Van Der et al. 2009) have been proposed in order to facilitate this process, although their use is still quite limited. To overcoming the barrier of nomenclature, it is crucial for every study to define strictly the terms used at the beginning of the mapping process.

Bottleneck 3. Skills and background

Refers to the skills and the disciplinary background of the people involved in the mapping process as map-makers or map-users. It is related to insufficient or unsustainable training but also to the incorporation of multiple disciplines within interdisciplinary science such as ES science and to the selection of participants for expert-based or PGIS mapping exercises. Spatial analysis and data visualisation are complex processes requiring a wide range of expertise from the thematic background and understanding the user requirements, to choosing the optimal methodology, selecting the appropriate software, having the skills to analyse data and designing a map. For example, mappers using online participatory mapping surveys have reported that the lack of intuitive controls has made the mapping complex and might have biased the answers towards people with higher computational skills (Muñoz et al., in prep.).

Some of the most widely used platforms for mapping ES, such as InVEST and ARIES, have long benefited from the provision of intensive training opportunities for map makers, which are an essential part for the distribution of these tools and for which significant resources need to be allocated Ruckelshaus et al. 2015, Villa et al. 2014. Training for map-users is also of particular importance given the risks of misinterpretation of model outputs and ES maps by users who may wrongly believe they understand them. In-model evidence tracking and guidance for interpreting model outputs and final ES maps can limit the resource-intensive requirement for map-users' training and support. Capacity building, innovative ES mapping guidance documents and user manuals, repositories of teaching materials and online discussion forums also aid wider use and application of mapping tools.

Regarding background-related skills, transdisciplinary education programmes and using systematic methods for stakeholder (map-makers and map-users) selection that account for multiple disciplines are needed. A user-friendly design of mapping methods, video tutorials and a section of Frequently Asked Questions (FAQ) have been applied to better guide mappers through the mapping process and to match users´ skills.

Bottleneck 4. Data and maps availability

Refers to limited availability or access to accurate, trustworthy and affordable data in the required format and at an adequate spatial or temporal resolution for the entire area of interest and to the availability of maps for map-users. ES maps availability is still a very significant constraint that practitioners face. A recent survey amongst 60 users of ES maps in sub-Saharan Africa found that only 27% of respondents had adequate ES data Willcock et al. 2016. This study reported the need of more dynamic ES information across spatial and temporal scales. Access to data and maps for map-makers and map-users is often complex since it can vary through different environmental, economic or social institutions/ authorities. Finding ways to access the specific materials and, more specifically, conquering the formal barriers, can consume more time and efforts than the mapping process itself. For example, in Poland, cooperation between public agencies, administration and research institutions that include access to data is pointed out as a main challenge for implementing ES in policy and decision-making Stępniewska et al. 2017. However, some recent government open data strategies are taking steps in some places to improve and in some cases, enforce the release of data from public agencies, which may improve access to datasets useful for ES mapping (e.g. Department for Environment et al. 2013/UK Defra Open Data Strategy, 2013).

In order to map ES, harnessing expert knowledge (e.g. through Bayesian Belief Networks, ES matrix/spreadsheet models or PGIS) has been widely applied in data-scarce regions (e.g.Burkhard and Maes 2017, Ricaurte et al. 2017, Verweij et al. 2016García-Nieto et al. 2015). Global, continental or regional datasets (e.g. Global Climate Monitor (http://www.globalclimatemonitor.org/), FAO soil maps (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en/), GlobCover (http://due.esrin.esa.int/page_globcover.php), CORINE land cover (http://land.copernicus.eu/pan-european/corine-land-cover) etc.) can also be used as data sources, in cases where there are no other available resources for data collection. The uncertainty inherited by the use of broad-scale datasets for local case studies should nonetheless be reported in the documentation of the final results. Remotely sensed data can also help to map certain ES when no on-ground information exists (or complement the existing information) and it will facilitate large-scale mapping of ES in the future (e.g.Asner et al. 2017, Bellamy et al. 2017, Franke et al. 2012, Roelens et al. 2016).

For instance, the Sentinel missions of Copernicus with improved spatial, spectral and temporal characteristics together with long-term historical satellite data can improve mapping and monitoring of ES. The use of new data sources such as social media to map cultural services or large data can also help to overcome this bottleneckWillemen et al. 2015a, van Zanten et al. 2016, Pastur et al. 2015. Citizen science coupled with applications of technology, such as the ES smartphone App MapNat, can help provide citizen science (crowd-sourced) data for ES maps Edsall et al. 2015 although lower confidence in some input data could increase uncertainty in the outputs. Improved systems for data sharing and journal or project requirements (i.e. the open access approach of EU Horizon 2020-funded projects) to make data freely available could also help solve this bottleneck. To increase the availability of maps, sharing platforms and communities of practice as described in bottleneck 1 are essential.

Some studies have opted to combine different methods in an attempt to tackle the scarcity of adequate data. In a study in South-Eastern Africa (Willemen et al., 2017), maps were derived from a combination of model-based maps and PGIS data in order to identify ES hotspots where these outcomes of the two approaches coincided in space. In some cases, despite the loss of information, simplification or generalisation can be a way forward to circumvent the lack of dataMeerbeek et al. 2016. In addition, models can be used to inter- and extrapolate data to regions where data is lacking Ottoy et al. 2017. At local scale, field measurements and observations often prove to be an efficient way forgaining new information or enriching existing data with important details (Kulczyk et al., forthcoming).

Bottleneck 5. Methods' selection

Refers to the difficulties experienced to select adequate methods because the differences amongst the multiple methodologies available and the resources needed to apply them is often unclear.

Applying integrated mapping steps ("tiered approaches") in which first the aim of mapping is defined, then the variables needed are identified and finally the method is selected, has been proposed for the identification and selection of methods (Grêt-Regamey et al. 2015). Decision trees that allow the selection of the adequate method based on the objective pursued, accuracy needed and data and resource availability can also help to identify the adequate methodology to use (Schröter et al. 2015). Applying different methodologies to map ES and comparing the results obtained considering their fit-for-purpose for different objectives (i.e. educational, heuristic, operational and political) can also help to select the most adequate method (Clec'h et al. 2016).

Several decision-making online platforms exist that allow the user to compare the different tools. For instance, the IPBES catalogue of policy support tools (in development), the UK-NEAT toolkit (http://neat.ecosystemsknowledge.net/), the ValuES platform (http://www.aboutvalues.net), The Ecosystems Knowledge Network's Tool Assessor (ttp://ecosystemsknowledge.net/resources/guidance-and-tools/tools/tool-assessor), the Ecosystem-Based Management tools platform (https://ebmtoolsdatabase.org) and the many methodological decision trees in the Guidance to ES Assessment (ttp://

www.guidetoes.eu). For the academic community, studies comparing model performance at catchment scale are available (e.g. Bagstad et al. 2016, Sharps et al. 2017, Vorstius and Spray 2015).

Bottleneck 6. Technical difficulties

Refers to technical issues experienced in the mapping process related to software or hardware constraints. GIS and spatial models, used to map ES, need to represent complex systems and so often require the use of large, complex datasets and intensive analysis. Technical difficulties include aspects such as how to digitise analogue participatory maps, count overlapping polygons, handling and analysing complex remote sensing data from different sources or developing an online platform for data gathering. Some tools are extensions to commercial, closed-code software (e.g. ArcGIS) to which not all users can readily or affordably access, thus restricting the community of users.

Multiple solutions to this bottleneck exist, such as user-friendly software development (including Open Source initiatives such as QGIS and QUICKScan), training through GIS courses, fast-evolving computation power and capabilities to store and analyse ‘big data’. Technical difficulties are often solved through openly accessible online blogs and forums. Growing communities of users can also be useful to share solutions to technical problems.

Bottleneck 7. Over-simplification

Refers to generalisation, as a key cartographic technique, that facilitates the representation of complex realities (Burkhard and Maes 2017). The simplicity of some ES maps might hide the complexities inherent to ES, including the multiple dimensions of values (monetary, ecological, social), or the different elements of the ES delivery chain. Moreover, ecosystem service values held by stakeholders, represent complex and sometimes abstract aspects that cannot easily be incorporated into a map (Nahuelhual et al. 2016). As values require an elicitation process to be formed and communicated, ES maps often do not contribute to the formation, expression and communication of broader pro-sustainability values. Adding multiple ES in just one map can hide important aspects that relate to only one service or one service category. This bottleneck also relates to the lack of communication of uncertainty and the lack of validation in ES maps. It is important thus to understand the limitations of ES maps and the non-neutrality - as in all types of maps and graphical representations – of the information they contain (Hauck et al. 2013).

Mapping ES supply, flow and demand (Syrbe and Walz 2012;Palomo et al. 2013;Baró et al. 2016) increases the complexity and challenges of ES mapping. However, ignoring processes such as ES demands tends to produce maps of priority areas in remote zones where benefits to society are relatively small (Verhagen et al. 2016). It can also generate maps that give a distorted perception of the scale and extent of a service flow (Drakou et al. 2017), or can limit the sustainability applications regarding the supply and use of ES (Burkhard et al. 2012;Quintas-Soriano et al. 2014).

Combinations of different methods such as field observations, PGIS, satellite images or model-based data to map ES have been suggested to obtain information from different sources and of different qualities that can overcome the over-simplification and help to reduce uncertainty (Bagstad et al. 2016; Kulczyk et al., forthcoming). Mapping the ecological, socio-cultural and economic values of ES and integrating these dimensions in a transdisciplinary manner can reduce common over-simplifications (Groot et al. 2010; Martín-López et al. 2014). Moreover, illustrating how ES are co-produced in complex social-ecological systems in ES maps can contribute to assessing the links between ES and sustainability (Palomo et al. 2016). Ideally, to reduce the over-simplification bottleneck, a portfolio of maps should be presented. This could include maps of ES potential, use and demand, maps that integrate different ES value-dimensions, maps that make explicit landscape complexities (ES bundles, trade-offs and synergies) or interactive maps that increase the level of detail shown (and information contained) at different scales of visualisation.

Discussion

Seven common bottlenecks have been presented that scientists and practitioners face when mapping ES. Despite not being exhaustive, it is considered that this classification is the first to contain the most common challenges faced in ES mapping to date. Even though various and diverse bottlenecks exist, there is as well a wide diversity of solutions. Some solutions demand more effort, time and resources than others, but for many cases simple solutions are available at hand for most ES mapping scientists and practitioners. A limitation of this study is that most respondents of the semi-structured questionnaire focused on map-making and have less experience in informing policy- and decision-making with ES maps as other ES practitioners. Recent research shows that current ecosystem service studies do not provide the adequate information that decision-makers need to make instrumental decisions (Wright et al. 2017) and that more detailed analysis of practitioners and end-user challenges regarding ES maps is needed (Klein et al. 2015).

Several bottlenecks are inter-related, which can lead to trade-offs and synergies amongst different solutions. For example, communication between map-makers and map-users (bottleneck 1) relates to the oversimplification challenge (bottleneck 7) and ways to communicate complex information efficiently, revealing a trade-off between the two. In some cases, end-users might require a less complex mapping output for their decision-making, which might fail to give a good representation of reality. A trade-off exists between harmonising context specificities with standardised approaches and using context-adapted approaches, that become clear with the issue of ES classifications. It is still to be seen if less strictly delineated classification systems can help to cope or solve this issue or if the use of linking data standards can help deviate from this issue. In other cases, solving one bottleneck (e. g. skills and background) can help through the whole mapping process.

Technology might help to solve some of the bottlenecks identified, especially with the help of cloud computing, data standards, remotely sensed data and software development. However, continuous communication and interaction with map-users, open access data and tool sharing and capacity building hold great potential for solving many of the bottlenecks presented here. Larger and more active integrative communities of map-makers and map-users are cornerstones for solving these challenges and for identifing others. Creative thinking, such as the use of social media data to map ES, can also help overcome several of the identified bottlenecks. Certainly, no magic or one-fits-all solutions exist and obtaining robust and end-user relevant maps demands a considerable amount of resources. Importantly, there is a danger of over-simplification while using ES maps that needs to be solved with high transparency, clear documentation of metadata and maps of uncertainties, portfolios of maps, multidimensional mapping and thorough dedicated communication with the end-users with the use of available expertise (e.g. there are experts dedicated in science communication or visualisation who are rarely involved in the process).

Expectations regarding the impact of ES maps and mapping process are high. In the near future, it can be expected that ES mapping will support a more sustainable and equitable use of nature and landscape planning, with as little uncertainty as possible and increased awareness of our dependence on nature. For that to happen, the ES mapping community could focus on dealing with the challenges presented here. To fully realise the potential of ecosystem service maps for sustainability, the bottlenecks presented above need to be solved first.

Conclusions

Mapping ES has become one of the most prolific fields within ES science. Despite all progress made, several challenges still remain for map-makers and map-users through the complex process of mapping ES and informing policy with ES maps. Here a classification is presented of seven mapping bottlenecks and related solutions identified by experts to improve : i) map-maker map-user interaction; ii) nomenclature and ontologies; iii) skills and background; iv) data and maps availability; v) methods-selection; vi) technical difficulties; and vii) over-simplification of mapping process/output. The synergies and trade-offs amongst solutions identified here can help to enhance the impact of the ES mapping community and to fully realise the potential of ES maps to inform decision-making.

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Conflicts of interest

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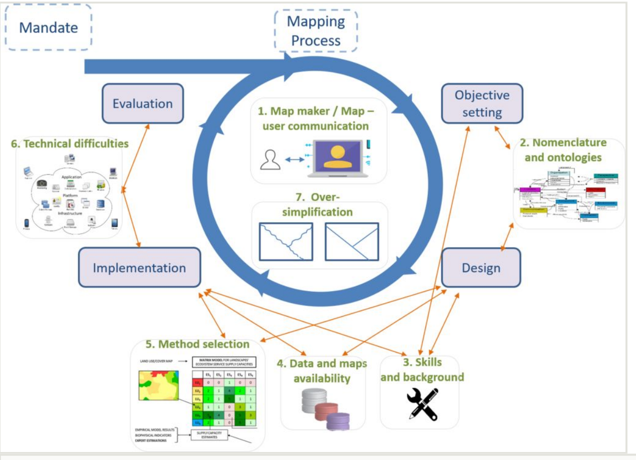

Figure 1.

Ecosystem service (ES) bottlenecks in ES mapping along the planning cycle. Modified from *Liu and Opdam (2014)*. Several bottlenecks can emerge in different phases of the mapping process or continously through it as bottlenecks 1 and 7.

Table 1.
Ecosystem services (ES) mapping bottlenecks and solutions offered around them.

Bottleneck	Description	Solutions for map-makers
1 Map-maker and map-user communication	Maps do not match users' needs due to the lack of requirement assessments	Iterative scientific-practitioner processes, transparent mapping proccesses, PGIS, usability analysis
2 Nomenclature and ontologies	Barriers related to ES classifications and terminology	ES free-listing based on socio-cultural assessments, classifications based on ontologies, flexible classification systems, pre-testing classifications with diverse stakeholders across scales, linked data standards
3 Skills and background	Insufficient training, lack of interdisciplinarity	Harmonised capacity building, training in mapping platforms, tutorials and guidelines, interdisciplinarity in scientists
4 Data and maps availability	Lack of adequate data	PGIS, remote sensing data, citizen science, social media data, use of existing data collected for other purposes, field observations and measurements
5 Methods selection	Difficulties experienced to select adequate methods	Tiered mapping approaches, decision trees, guidelines for standardised mapping/measurements of ecosystem service
6 Technical difficulties	Technical issues related to software, IT-infrastructure, capacity	User friendly software, better computation power, training, blogs/ forums, larger communities of mappers
7 Over-simplification	Hindering of complexity inherent in ES	Combination of approaches, mapping different value dimensions, co-production of ecosystem services