Mapping Ecosystem Services

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Why is Mapping Ecosystem Services important?

Ecosystems perform a variety of functions, the outcomes of which are recognised as 'ecosystem services' when humans benefit either directly or indirectly from them. To understand ecosystem service provision there is a need to identify both where they are generated and where they are received (Fisher et al., 2011). The area of effect associated with an ecosystem service ranges from *in situ* benefits (such as the provision of shelter) that have no flow component, to benefits realised at a global scale (such as mitigation of climate change through increased carbon storage). Understanding the supply and demand depends not only on knowing how much of a service is produced, but also when and where (Troy and Wilson, 2007; Swetnam et al., 2011). Given the fundamental importance of taking a spatially explicit approach, there are now a rapidly growing number of methodologies available for mapping and modelling ecosystem services (these are reviewed in Burkhard et al., 2012; Egoh et al., 2012; Crossman et al., in press).

Much of the early work on mapping ecosystem services focused on identifying where the stocks of natural capital associated with the delivery of particular ecosystem services were within a study area. Mapping the areal extent and spatial configuration of landscape features (such as woodlands, wetlands and rivers) are key factors in determining both the type and value of the ecosystem service produced (Morse-Jones et al., 2011). These stocks are seldom static, as changes in land use and climatic variation for example, can have both short-term and long-term impacts on land cover, which in turn impacts their ability to provide services (MA , 2005). As the distance between where services are generated and where they are received increases, the potential value of the service can also change as can the likelihood of its value being overlooked in decision-making. This will be influenced both by bio-physical factors, such as topography, or social factors such as variation in the number of uses and users of a service and the scarcity or abundance of the benefit within receptor populations. Increasingly, work on mapping ecosystem services has focussed on developing methodologies to better capture these dynamics (Bagstad et al., in press; Palomo et al., in press).

Mapping techniques provide a powerful tool for communication and to support decision-making. They facilitate the integration of complex, interdisciplinary information related to ecosystem services into landscape management and environmental decision-making (Balvanera et al., 2001; Daily and Matson, 2008; Swetnam et al., 2011). If more holistic approaches to the management of ecosystem services are to be adopted then there is also a need for consideration of where synergies and trade-offs occur between ecosystem services (de Groot et al., 2010). Currently, few mapping approaches have gone much beyond presenting a series of maps for the services of interest. Sometimes, services are bundled at source, but this may obscure the effect of management options if the bundled services have different flow pathways.

This tool is closely linked to GIS Tools for Stocks and Flows of Ecosystem Services

When and why should I use the tool?

It may be appropriate to use maps in a range of circumstances. Maps are important across the spectrum of activities associated with the Ecosystem Approach and, as such, they are a key element of Ecosystem Service Assessments [Hyperlink]. In particular, mapping of ecosystem services is useful for:

a) identifying where ecosystem services are produced and for consideration of the scales at which they manifest,

b) strategic and operational decision-making relating to the exploitation of ecosystems services in a way that is compatible with sustainable development principles (for example in spatial planning or in scenarios work),.

c) understanding the flow and value of benefits to human populations (ecosystem service valuation),

d) determining synergies and trade-offs between ecosystem services (this is important for management and evaluation), and

e) engagement and communication amongst stakeholders. Given the requirement for interdisciplinary and participatory approaches envisioned by the ecosystem approach (Cowling et al., 2008), maps provide an intuitive, visual means of communicating information amongst stakeholders.

What is its relevance to the Ecosystem Approach and ecosystem services?

Ecosystem service mapping has been identified as particularly important in the transition to operational planning and real-world implementation of an ecosystem approach (Boumans and Costanza, 2007; Fisher et al., 2009; de Groot et al., 2010)

The CBD guide for the Ecosystem Approach states that spatially explicit understanding is required to analyse and understand the temporal and spatial scales at which ecosystem functions operate, and the effect of management actions on these processes and the delivery of ecosystem goods and services. The quantification and mapping of ecosystem services are considered as one of the main requirements for the implementation of the ecosystem services concept into environmental institutions and decision-making (Burkhard et al., 2012).

How does one work with the tool in practical steps?

Given the wide range of potential applications of mapping within the ecosystems approach, it is difficult to provide generic guidance. There has been exponential growth in the development of ecosystem service mapping approaches and there is no uniform way to approach the task. However, a number of principles are common to all ecosystem service mapping, and these are discussed below.

Basic considerations

There are four key questions that should be considered before mapping begins

1. What ecosystems are being mapped?
2. What is the scale of the maps?
3. Who is the target audience for the maps?
4. What are the functions of the maps?

What constitutes a functional unit for the supply of ecosystem services is determined partially by the requirements of the observer and partially by the scale of observation. Variation in these parameters can have a strong influence on how landscape functions are perceived and measured. At a landscape scale, an example of a functional unit could be a woodland block, where the assemblage of abiotic and biotic components (trees and associated biota) combine to provide a distinct set of services which differ from neighbouring land uses (such as arable fields).

We can think about mapping ecosystem services at a range of scales. Explicit consideration of the scales at which various services manifest is required for valuation (Hein et al., 2006; Kozak et al., 2011). The three most common scales mapped are:

- **National scale** is defined here as the scale at which strategic decisions about ecosystem services are made. This encompasses supranational transboundary contexts in some locations (e.g. some major lakes and protected area networks). Assessments at national scale tend to use aggregated national datasets, which are generally very coarse in their spatial resolution.
- **Regional scale** is defined here as the scale between local and national. This is the scale at which many policy decisions relating to ecosystem service provision are currently made and is generally over 1000 km^2 but sub-national. The resolution required to support regional decisions is generally quite coarse.
- **Local scale** is the scale at which ground level decisions about change in land use are made. The main actors at this scale are farmers, forest managers or other land users. It encompasses fields and farms up to an immediate landscape scale of 10 to 1000 km2 at which ecosystem services are initially manifest (e.g. sub-catchments or habitat networks), and may be managed through farmer co-operatives or other collectives covering a contiguous land area. Maps generated at these scales are often designed to allow farmers to see their land in a recognisable context and thus require fine resolution datasets.

Currently most of the mapping approaches available focus on national and regional scale output.

This guidance uses an organising framework developed by Pagella and Sinclair (in review). This classifies ecosystem service maps into 18 broad categories (Figure 1). This drew on various recent studies (Fisher et al., 2009; de Groot et al., 2010; Morse-Jones et al., 2011; Cowling et al., 2008) to augment the basic stock-flow-receptor model of Haines-Young et al. (2009). The types of maps are arranged sequentially, showing how some maps are used in developing others. This framework incorporates a temporal dimension and explores where synergies and trade-offs amongst services can be mapped.

The 16 types of maps and the interactions amongst them are discussed below, referring to nodes in Figure 1 by their alphanumeric coding.

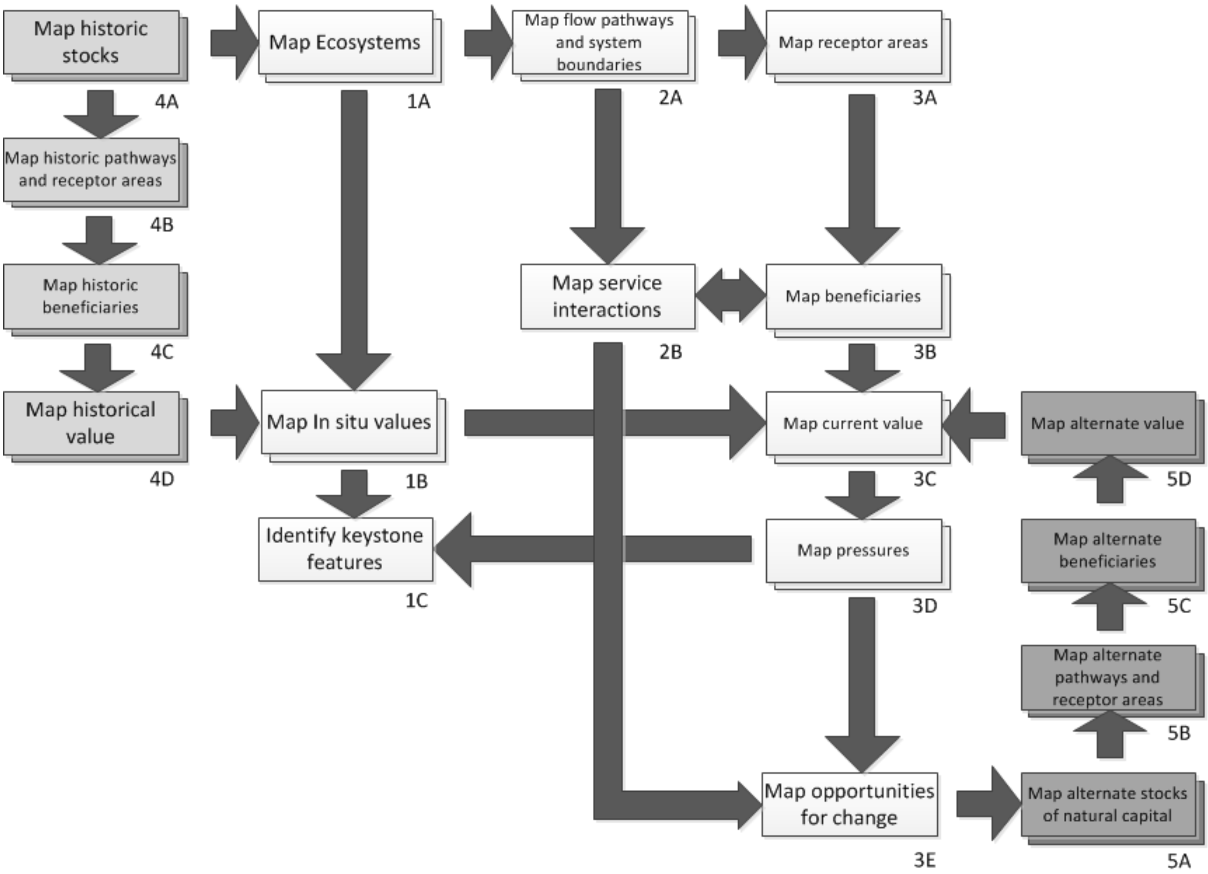

Figure 1

Mapping ecosystems

Ecosystem mapping is the spatial delineation of ecosystems following an agreed ecosystem typology (ecosystem types) (Maes et al., 2013). The spatial arrangement, quantity and composition of ecosystem types within a landscape will have a strong influence on the ecosystem services generated (node 1A). This is scale dependent and the resolution and precision will vary as we move from national to local scale maps (i.e. national scale maps may only recognise major woodlands whereas local scale makes may include trees)

Ecosystem functions represent the capacity of ecosystems to provide goods and services both directly and indirectly (de Groot et al., 2010). Associating functions to ecosystem types allows a set of functional units to be defined. This can be done for a range of individual ecosystem services (see, for example, the Joint Nature Conservation Committee (JNCC) report on the spatial mapping of ecosystem services. By identifying functional units within ecosystem types it is possible to identify in situ values (node 1B), using, for example, benefit transfer approaches, where values are assigned to objects with specific characteristics and later used to assign values for objects with similar properties in other systems (see Lautenbach, 2011; Troy and Wilson, 2006).

Bundling ecosystem functions together within a single functional unit enables identification of keystone landscape features. These are, in effect, hotspot (or coldspot) areas (node 1C). An example of this is work done by Egoh et al. (2008). Note that these valuations are in situ, focussed solely on the point of generation and do not acknowledge variation in their reception. They are therefore not truly maps of ecosystem services.

Mapping flow pathways

Mapping the position of ecosystem types will provide information about the nature and strength of services being provided at source, but mapping flow pathways is required to establish the area of effect and who will benefit (node 2A). Linking ecosystem services to human wellbeing requires identification of the receptor areas (or boundaries) for ecosystem services which, in turn, are fundamental for appraising their economic value. Methods for mapping ecosystem service flow pathways are still in their infancy (Morse-Jones et al., 2011). The development of a systematic approach to the quantification of ecosystem service flows has been an area of focus for recent work (Bagstad et al., in press; Palomo et al., in press)

There may also be interactions amongst ecosystem services along their flow pathways, and at the places where they are received, influenced by the medium of delivery. Potential water quality benefits delivered by woodlands, for example, may be diluted by inputs from intensive agriculture further downstream that breach a quality threshold. Explicitly identifying synergies and trade-offs amongst ecosystem services (node 2B) is fundamental to managing them for broader societal benefits

Mapping beneficiaries

To link ecosystem functions and benefits to human wellbeing requires acknowledgement of where the benefits of ecosystem services are manifest (node 3A). Understanding the linkages between areas where ecosystem services are generated and where they are received is important for policy development, because, decisions by 'upstream' stakeholders to meet local requirements, may lead to positive or negative consequences from the perspective of 'downstream' stakeholders, at larger scales (Hein et al 2006). Once receptor areas have been identified, then stakeholders who benefit ('beneficiaries') and those who either do not receive services ('neutrals') or who see a decrease in service supply ('losers') can be identified (node 3B). This approach facilitates a 'needs analysis' that can in turn inform strategic decision-making, though this is often complicated because stakeholders may be winners within the context of some ecosystem services and losers in relation to others, especially when evaluated over longer time horizons. The identification of beneficiaries allows spatially explicit representation of ecosystem service values. This in turn allows identification of strategies for equitable modifications to ecosystem service provision (node 3D).

Operational decision-making requires spatially explicit identification of opportunities for interventions to improve ecosystem service provision (node 3E). This involves mapping the areas where modifying land use or cover has the greatest likelihood of impacting ecosystem services in relation to management objectives and taking into account impacts on services and stakeholders who are likely to be affected by the interventions.

Finally, values (nodes 3C, 4D and 5D) can be assigned and mapped for past, present, future or alternative scenarios of ecosystem provision.

Mapping changes over time

Provision of ecosystem services is dynamic through time as well as space, so that developing a spatially explicit understanding of trends in the supply of ecosystem services is required for the management of these services. Mapping the impacts of historic land use change helps to explain variation in current ecosystem service supply and may help identify interventions to address shortfalls in delivery where reversion of land use change is appropriate. Mapping both historic land cover (node 4A) and historic transformations (node 4B – 4C) can provide valuable insight into both current and future ecosystem service delivery and feed into identification of opportunities for interventions (node 2C) (see Reyers et al., 2009, for an example). In a similar way, consideration of future drivers of land use change (e.g. the effects of climate change) or exploration of alternative scenarios for land use, requires development of future or alternate land use maps (node 5A) that can be used to inform models of ecosystem flows (5B). These can then be used to map potential impacts (node 5C) both in terms of winners and losers.

Mapping as a tool for communication

Operational decision making within an Ecosystem Approach framework requires interaction between individuals or agencies with different responsibilities or expertise (e.g. forestry and agriculture). At strategic scales, the mapping of ecosystem services has been recognised as a key element to improve inter-institutional understanding for natural resource management (de Groot et al., 2010; Pettit et al., 2011). Maps provide intuitive and simple methods for communicating information amongst stakeholders (resource managers and members of the public) about the complex interactions between ecosystem services at a range of spatial and temporal scales (Cowling et al., 2008).

Wider considerations and assumptions of good practice and pitfalls of which the user needs to be aware

Mapping of ecosystem services is an area of very active development. There have been calls for more uniform methodologies to facilitate cross-site comparisons and improve valuation work [REF}.

Data

Currently, one of the key constraints to mapping ecosystem services consistently is a lack of data. Common to other forms of evaluation, there are frequently issues with identifying appropriate indicators and data to map the broad range of ecosystem services. Given the paucity of data it is common to use proxies for ecosystem services in mapping, most commonly land cover data (ignoring abiotic components). The use of proxies has been demonstrated to have a high potential for error (Eigenbrod et al., 2010).

At the other end of the spectrum, there is a need to develop mapping methodologies, particularly in relation to ecosystem service flow pathways, in order for decision makers to better understand who the beneficiaries of ecosystem services are, along with their perceptions of the value of ecosystem services (Petter et al., 2013).

Number of services

Given the issues with data, it is not uncommon for mapping studies to address a limited selection of ecosystem services. This may be appropriate in many instances, but most studies are not explicit about the reasons for selecting a subset of services. A recent review of mapping approaches by Crossman et al. (in press) identified the most commonly mapped ecosystem services as climate regulation, recreation and tourism, food supply, provision of water and regulation of water flows. The majority of studies mapped one individual service and the average number of mapped ecosystem services per study was 5.6. (n=113). As Crossman et al. suggest, there is often no way of knowing whether an ecosystem service is absent from a study because it is locally unimportant or because the data were not available or collected.

Another approach observed in an international review of "Payments for Ecosystem Services" (PES) projects (Schomers and Matzdorf, 2013) observed that most schemes take an 'environmental services' approach by valuing a linked 'basket' of services that are provided by, or assumed to be provided by, habitat units maintained in an acceptable state. In practice, many services provided by woodlands, wetlands and other habitats are co-produced through sensitive management, so private markets for individual services can be linked to state-vectored markets which protect overall ecosystem service provision for the wider benefit of the public.

Scale

While the ecosystem approach can be applied to issues at any scale, it is important to be explicit about the scales at which maps are developed in relation to the scale of analysis and action. Boundaries for management are defined operationally by users, managers, scientists and by local and indigenous peoples. There are potential mismatches between administrative boundaries and ecosystem service boundaries, particularly as system boundaries may differ with each ecosystem service [http://www.cbd.int/doc/programmes/cro-cut/eco/eco-guide-ad-en.pdf]. There may also be perverse political boundaries to consider, for example where levies on properties to address flood risk cannot be spent beyond municipality boundaries in upstream catchments where the optimal areas for natural floodwater retention may be located.

Related to scale is the issue of resolution. If the ecosystem service being considered is carbon sequestration for example, then it is relatively straightforward to distinguish between functional units such as woodland blocks and arable fields, in their time-averaged carbon storage. Individual trees and hedgerows also sequester carbon, at varying degrees depending upon their age and location, but are generally too small in extent to be represented in land cover datasets. As a result, these isolated trees and linear hedgerow features may not be well-mapped and their collective impact may not be taken into consideration, despite their potential significance when aggregated at a landscape scale (Pagella and Sinclair, in review). Where decisions are being made at scales where these features become significant, there is a clear requirement for datasets to be have sufficient resolution to represent them.

Useful links

The **Ecosystem Services Partnership** has a thematic work group dedicated to mapping ecosystem services

PRESS, (PEER Research on Ecosystem Services). The PRESS project (EU-JRC) is designed to deliver innovative scientific research products with immediate policy relevance and to facilitate interaction with national and European stakeholders from all relevant policy domains. They have produced a range of national scale mapped outputs

There is a growing collection of examples of mapping of ecosystem services in the UK http://www.valuing-nature.net/news/2012/new-online-resource-ecosystem-service-mapping-projects

Some examples of local mapping work include

Polyscape

This is a negotiation support tool that maps how land use changes at field level, such as changes in tree cover, impact a range of ecosystem services The tool allows stakeholders to explore how different land use scenarios impact each ecosystem service individually and synergies and trade-offs amongst them.

Polyscape - Cambrian Mountains Initiative

The Westcountry Rivers trust

http://wrt.org.uk/wordpress/?p=294

EcoServ-GIS is a Geographical Information Systems (GIS) toolkit that generates fine scale (10 or 50 m resolution) maps illustrating the requirement for each service as well as the capacity for service provision, using scientifically-based, standardised methods and widely available datasets. http://www.durhamwt.co.uk/what-we-do/current-projects/ecoserv-project/

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