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A blueprint for mapping and modelling ecosystem services

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ABSTRACT

The inconsistency in methods to quantify and map ecosystem services challenges the development of robust values of ecosystem services in national accounts and broader policy and natural resource management decision-making. In this paper we develop and test a blueprint to give guidance on modelling and mapping ecosystem services. The primary purpose of this blueprint is to provide a template and checklist of information needed for those beginning an ecosystem service modelling and mapping study. A secondary purpose is to provide, over time, a database of completed blueprints that becomes a valuable information resource of methods and information used in previous modelling and mapping studies. We base our blueprint on a literature review, expert opinions (as part of a related workshop organised during the 5th ESP conference[2]) and critical assessment of existing techniques used to model and map ecosystem services. While any study that models and maps ecosystem services will have its unique characteristics and will be largely driven by data and model availability, a tool such as the blueprint presented here will reduce the uncertainty associated with quantifying ecosystem services and thereby help to close the gap between theory and practice.

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1. Introduction

Ecosystems provide various goods and services to society, which in turn directly contribute to our well-being and economic wealth (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005; TEEB, 2010; de Groot et al., 2012). Valuing the contribution of ecosystems to human well-being through economic, ecological and social (triple-bottom-line) accounting such as Green GDP (Boyd, 2007), the United Nations System of Environmental Economic Accounts (United Nations Statistical Division, 2012), the Green Economy (United Nations Environment Program, 2011), and corporate sustainability reporting (World Business Council for Sustainable Development, 2010) demands robust methods to define and quantify ecosystem services. Also, decision making and policy aimed at achieving sustainability goals can be improved with accurate and defendable methods for quantifying ecosystem services (McKenzie et al., 2011). As Troy and Wilson (2006) point out, spatially explicit units are needed to quantify ecosystem services because supply and demand for ecosystem services are spatially explicit. Furthermore, the supply and demand of services may differ geographically (Fisher et al., 2009; Bastian et al., 2012a). This heterogeneity calls for maps of ecosystem service supply and demand. Distinguishing between mapped supply and demand provides a basis for accounting to ensure demand does not exceed supply. Hence, mapping is a useful tool for illustrating and quantifying the spatial mismatch between ecosystem services delivery and demand that can then be used for communication and to support decision-making.

A number of recent studies have mapped the supply of multiple ecosystem services at global (Naidoo et al., 2008), continental (Schulp et al., 2012), national (Egoh et al., 2008, Bateman et al., 2011) or sub-national (Nelson et al., 2009, Raudsepp-Hearne et al., 2010, Willemen et al., 2010) scales. A few recent studies have mapped the demand of ecosystem services (Burkhard et al., 2012b, Kroll et al., 2012, Nedkov and Burkhard, 2012, Palomo et al., in press). Other recent studies offer frameworks for

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integrating the ecological and economic value-dimensions of ecosystem services to more accurately calculate monetary values of mapped ecosystem services (Daily et al., 2009, de Groot et al., 2010, Wainger and Mazzotta, 2011). There have also been a number of reviews (Egoh et al., 2012, Martínez-Harms and Balvanera, 2012), special issues of journals (Burkhard et al., 2012a, Crossman et al., 2012b) and books (Kareiva et al., 2011) on ecosystem services quantification, modelling and mapping. These products are at numerous scales and demonstrate the many and diverse ways to model and map ecosystem services. Consequently, there is much uncertainty in what is mapped and the methods used to map the services.

The inconsistency in methods to quantify and map services (Eppink et al., 2012) is a challenge for developing robust economic, ecological and social values of ecosystem services for inclusion in national accounts and broader policy and natural resource management decision-making. At a broader level of sustainability policy, there needs to be better understanding of where and what services are provided by a given piece of land, landscape, region, state, continent and globally, so that stocks of natural capital and the flow of services can be monitored and managed across spatial and temporal scales. There also needs to be better understanding of conditions and threats to the natural capital so that finite resources can be targeted to where the enhancement of services is needed most (de Groot et al., 2010). Furthermore, the recent biodiversity conservation policies based on commodification of ecosystem service production, such as payments for ecosystem services, biodiversity and wetland banking, carbon offsets and trading, and conservation auctions, depend on robust measurement on the stocks of natural capital and flow of services to provide surety to participants in these markets. The varied methods also make the commodification and trade of ecosystem service values very difficult because markets require certainty and clarity around the product being traded, both in the supply-side and the demand-side. The varied methods also make public and private sector ecosystem service accounting very difficult for the same reasons.

Recently, Martínez-Harms and Balvanera (2012) call for a standardised methodological approach to quantify and map ecosystem services, Eppink et al. (2012) suggest that an adaptable conceptual framework should be developed for ecosystem service assessments and Maes et al. (2012a) call for a consistent ecosystem service mapping approach. On a more practical level, TEEB (2010) call for extra effort in mapping: (i) the flow of services; (ii) a wider set of ecosystem services that includes cultural and regulating services, so trade-offs can be better explored, and; (iii) the connections between biodiversity and the final benefit. The conceptual framework, presented in Seppelt et al. (2012) as a blueprint for ecosystem service assessment, includes a component for describing the indicators and their calculation, but little prescriptive detail on modelling and mapping. There is clearly a need to develop a blueprint and set of standards for mapping the stocks and flows and supply and demand of a fuller suite of ecosystem services.

In this paper we develop and test a blueprint for modelling and mapping the stocks of natural capital and flows of ecosystem services, building on the Seppelt et al. (2012) ecosystem service blueprint by focusing on the specific mapping aspect. For simplicity, we use term *ecosystem services* in place of *natural capital stocks and ecosystem service flows*. In this paper we do not limit ourselves to any types of ecosystem services, but instead follow the precedent set by TEEB (2010), who valued elsewhere classified *intermediate* and *final* services as long as the services provide an indirect or direct contribution to human well-being (see Box 1). Our premise is that a review of existing techniques used to model and map ecosystem services provides the basis for the blueprint. We review the current state of the art in mapping ecosystem services, taking into account existing ecosystem service mapping tools and preceding reviews. Our review focuses on the modelling and quantification methods used to map each ecosystem service. We provide preliminary results of our review and a description of the methods used for each of the main ecosystem services mapped. We then propose a blueprint as a guide for mapping ecosystem services, followed by a completed example of the blueprint. The blueprint was developed with the input from working group participants at the 5th Ecosystem Services Partnership Conference in Portland, Oregon, August 2012. We conclude with a discussion on where our approach could be of most use, and provide some critical thought on the level of uncertainty that is inherent in any effort to map ecosystem services.

Box 1–Ecosystem service definitions.

Ecosystem services: contributions of ecosystem structure and function—in combination with other inputs—to human well-being (Burkhard et al., 2012a).

Ecosystem processes: changes or reactions occurring in ecosystems; either physical, chemical or biological; including decomposition, production, nutrient cycling and fluxes of nutrients and energy (Millennium Ecosystem Assessment, 2005).

Ecosystem structures: biophysical architecture of ecosystems; species composition making up the architecture may vary (TEEB, 2010).

Ecosystem functions: intermediate between ecosystem processes and services and can be defined as the capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly (de Groot et al., 2010).

Intermediate ecosystem services: biological, chemical, and physical interactions between ecosystem components. E.g., ecosystem functions and processes are not end-products; they are intermediate to the production of final ecosystem services (Boyd and Banzhaf, 2007).

Final ecosystem services: Direct contributions to human well-being. Depending on their degree of connection to human welfare, ecosystem services can be considered as intermediate or as final services (Fisher et al., 2009).

Ecosystem service supply: refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period (Burkhard et al., 2012b). Depends on different sets of landscape properties that influence the level of service supply (Willemen et al., 2012).

Ecosystem service demand: is the sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period (Burkhard et al., 2012b).

Ecosystem service providing units/areas: spatial units that are the source of ecosystem service (Syrbe and Walz, 2012). Includes the total collection of organisms and their traits required to deliver a given ecosystem service at the level needed by service beneficiaries (Vandewalle et al. 2009). Commensurate with *ecosystem service supply*.

Ecosystem service benefiting areas: the complement to ecosystem service providing areas. Ecosystem service benefiting areas may be far distant from the relevant providing areas. The structural characteristics of a benefiting area must be such that the area can take advantage of an ecosystem service (Syrbe and Walz, 2012). Commensurate with *ecosystem service demand*.

Ecosystem service trade-offs: The way in which one ecosystem service responds to a change in another ecosystem service (Millennium Ecosystem Assessment, 2005).

2. State of the art in mapping ecosystem services

2.1. Ecosystem service mapping tools

A widely applied ecosystem service mapping and valuation tool is InVEST (Kareiva et al., 2011), the Integrated Tool to Value Ecosystem Services and their trade-offs. It is an open access GIS-tool collection developed under the Natural Capital Project[3] . It includes separate models for different ecosystem services to be applied and combined to analyse spatial patterns of ecosystem services or track changes caused by land cover change. The complexity of the models available in InVEST varies from proxy-based mapping (tier 1) to simple biophysical production equations (tier 2). But the tool has the ability to include third-party complex, site-specific process models (tier 3). The main inputs to InVEST are land cover data and other environmental variables as relevant, and outputs are the estimate of ecosystem services in biophysical and in some cases monetary units. InVEST has been used to map and value ecosystem services under different land cover scenarios in Oregon, the United States (Nelson et al., 2009) and Tanzania (Swetnam et al., 2011). Bai et al. (2011) used InVEST to analyse the spatial correlations between biodiversity and ecosystem services in a Chinese case study and Guerry et al. (2012) used InVEST to quantify ecosystem services in a marine case study in Canada.

Further ecosystem service mapping tools of note are ARIES (Villa et al., 2009), the ARtificial Intelligence for Ecosystem Services[4] , SolVES (Sherrouse et al., 2011), the Social Values for Ecosystem Services[5] , and GUMBO, the Global Unified Metamodel of the BiOsphere[6] . ARIES is a web-based ecosystem services mapping and valuation tool, which uses probabilistic Bayesian networks to analyse ecosystem service flows from point of supply to place of use and beneficiaries. SolVES is a GIS tool to assess, map, and quantify the perceived social values for ecosystems, such as aesthetics, biodiversity, and recreation. GUMBO uses simulation modelling to model global dynamics and interactions of natural capital with built, social and human capital.

2.2. Existing reviews

Two recent reviews by Martínez-Harms and Balvanera (2012) and Egoh et al. (2012) summarise the recent literature on mapping ecosystem services. Using the Web of Science ISI Web of Knowledge, ScienceDirect, and Google Scholar, Martínez-Harms and Balvanera (2012) identified 70 publications published from 1995 to 2011 that have mapped the supply of ecosystem services.

Egoh et al. (2012) reviewed the indicators, methods, and data types that have been used to map and model ecosystem services. Using Scopus and ScienceDirect, they identified 67 publications published between 1997 and 2011 that mapped and/or modelled ecosystem services. The parameters assessed in each review are presented in Table 1. For comparison we include in Table 1 the parameters assessed in our review (see next section for detail).

The main findings of Martínez-Harms and Balvanera (2012) are (following the ecosystem service typology used by the authors):

- The ecosystem services most commonly mapped are, in descending order: carbon storage (in 13 publications; 19% of total); carbon sequestration (11; 16%); food production (11; 16%); recreation (9; 13%); provision of water (7; 10%) and water quality (7; 10%).
- Secondary data (land cover, remotely sensed and topographical data) are more commonly used (59% of services reviewed) to map ecosystem services, especially the regulating ecosystem services.
- Regional-scale dominates the published mapping studies (57% of services reviewed), followed by the national scale (15%).
- Causal relationships (using existing knowledge about the relationship of ecosystem service supply to environmental variables) is the most common method (37% of services reviewed) used to map ecosystem services, followed by extrapolation of primary data (20%).

Table 1
Comparison of approaches used in recent reviews of mapping ecosystem services.

Criteria	Martínez-Harms and Balvanera (2012)	Egoh et al. (2012)	Our review
Number of papers reviewed	70	67	122
Type of ecosystem service	Yes	Yes	Yes
Sources of data/ indicators	Yes	Yes	Yes
Types of data	Yes	Yes	Yes
Scale/ Resolution	Yes	Yes	Yes
Method	Yes	Yes	Yes
Extent of study area	No	Yes	Yes
Country	No	Yes	Yes
Reason for mapping	No	Yes	No
Habitat type	No	No	Yes
Valuation method	No	No	Yes

The main findings of Egoh et al. (2012) are (following the ecosystem service typology used by the authors):

- Regulating services are mapped more frequently than other service categories. The most commonly mapped services are climate regulation (44 publications; 66% of total), food provision (37; 55%), recreation (35; 52%), regulation of water flows (28; 42%) and provision of water (21; 31%). On average, 3.9 ecosystem services were mapped per study.
- Proxy methods are the most commonly used method for mapping ES, despite their highest potential for error (Eigenbrod et al., 2010).
- Comparisons of mapped ecosystem services across studies are rarely applicable because many studies use unique primary indicators to map single ecosystem services, or multiple, different indicators are used in cases where single indicators are insufficient.
- The most common indicators for mapping ES are land use/ cover, soils, vegetation, and nutrient related indicators.
- Provisioning and regulating services are more commonly mapped at larger scales (national level or higher), followed by supporting and cultural services.
- Resolution of data used to map ecosystem services is dictated by the service being mapped. Ecosystem services with site-specific processes, such as pollination, demand higher resolution data whereas generic services, such as climate regulation through carbon sequestration, may be sufficiently mapped with coarser resolution data.
- The sub-national level is the most common scale of mapping ecosystem services.

The Martínez-Harms and Balvanera (2012) and Egoh et al. (2012) reviews have different purposes. In the former, the authors

[3] 〈http://www.naturalcapitalproject.org/InVEST.html〉
[4] 〈http://www.ariesonline.org/〉
[5] 〈http://solves.cr.usgs.gov/〉
[6] 〈http://ecoinformatics.uvm.edu/projects/the-gumbo-model.html〉

reveal trends in the main ecosystem services used in decision-making, as well as trends in types of data and methods used to map ecosystem services, with the aim of using this information to make a number of suggestions for mapping ecosystem services that would result in estimates that are more defendable. For example, to avoid bad decision-making because of over-simplified maps, Martínez-Harms and Balvanera (2012) recommend regression models that reveal the relationship between field samples of ecosystem services and environmental variables. However, in the absence of sufficient time and resources for regression modelling on primary data, they suggest a good option would be to map ecosystem services based on causal relationships between primary and secondary data. The aim of the Egoh et al. (2012) review was to: (i) better understand the types of indicators and spatial or non-spatial data used to map ecosystem services globally; (ii) identify the main components that need to be taken into account for ecosystem service mapping; (iii) identify existing gaps both in ecosystem service mapping and available data, and; (iv) propose sets of indicators that could be used to map ecosystem services for which limited or even no mapping has been detected.

2.3. Our review

Our aim was to build on the Martínez-Harms and Balvanera (2012) and Egoh et al. (2012) reviews. We did this by firstly revisiting the papers reviewed in those two studies, as well as additional papers that were either not identified in those reviews or were published subsequently. We collected additional attributes used by the authors to map ecosystem services to give us a more complete dataset of methods and techniques, such as the habitat types mapped and, if applicable, the economic valuation method (Table 1). We identified all peer review papers from the electronic databases of the ISI Web of Science, Science Direct and, Google Scholar that included in the "Topic" the key word "ecosystem services" or similar, in combination with "mapping" or similar (Table 2). We then selected the papers that have at least one map representing particular aspect of ecosystem services. Our selection process identified 113 papers (see Online Supplementary Appendix 1), published until August 2012, containing a total of 615 attempts to map individual ecosystem services. There is some overlap between papers in our review and papers reviewed by Martínez-Harms and Balvanera (2012) and Egoh et al. (2012).

The number of studies mapping ecosystem services has grown exponentially, from one study in 1996 to more than 10 per year since 2008. Our review identified that regulating ecosystem services have been most often (46% of all services) mapped, followed by provisioning (30%), cultural (18%) and supporting/habitat (6%). The most commonly mapped ecosystem services identified in our review are climate regulation, recreation and tourism, food provision, provision of water and regulation of water flows. Most publications (36) mapped one individual service, while 17 publications mapped more than 10 services. The average number of mapped ecosystem services per study is 5.6. The continents where ecosystem services have been mapped more frequently are Europe (47 publications), North America (17), Asia (15), Africa (14), Australia and New Zealand (7) and South & Central America (3). The countries where ecosystem services have been mapped more frequently are China (14 publications), USA (12), Germany (8) and South Africa (7), while there are 24 publications mapping services in several countries (multi-national or global scale). The number of authors of each publication ranges from: 46 publications (1 to 3 authors), 51 publications (4 to 6 authors) and 16 publications (more than 7 authors).

We found that 51 different journals have published a paper mapping ecosystem services. The most frequent journals are Ecological Economics (16), Ecological Indicators (12), and the International Journal of Biodiversity Science Ecosystem Services & Management (11).The next sections summarise what we identify as the main methods used to map and model each ecosystem service which can inform us in developing a blueprint for future ecosystem service mapping and modelling studies.

Table 2
Keywords used in the bibliographic review in ISI Web of Science, Science Direct and, Google Scholar. Plural forms of the word were used where sensible.

Keywords referring to ecosystem services	Keywords referring to mapping
"Benefit transfer"	"Cartography"
"Ecosystem benefit"	"Distribution of benefits"
"Ecosystem good",	"Geospatial"
"Ecosystem service",	"Geographic information system"
"Environmental benefit"	"GIS"
"Environmental good"	"Landscape"
"Environmental service"	"Map*"
"Natural benefit"	"Regional"
"Natural good"	"Remote sensing"
"Natural service"	"Spatial*"
"Value transfer"	"Scale"

2.3.1. Provisioning services

2.3.1.1. Food. When multiple ES are mapped, food production is almost always included. Food production sourced from cultivated plants and domesticated animals is commonly mapped across large areas using coarse resolution land use data in combination with agricultural statistics. Land use data is generally not of sufficient spatial and data resolution to map to the level of commodity (crop type, livestock species). A small number of examples exist where detailed commodity mapping has been completed (Bryan et al., 2009, 2011a) by linking agricultural simulation process models to land use, soil and climate variables. Mapping food production at high spatial (e.g. 1 ha) and data (e.g. individual commodity) resolution across large areas (e.g. national, continental) requires resource-intensive process modelling and demands substantial computing power. A wide variety of units are used to express the level of food production, ranging from binary land cover types to kcal per hectare per year. Food production sourced from wild plants and animals is rarely mapped although Schulp et al. (2012) made an attempt by mapping wild food sourced from hunting data.

2.3.1.2. Water. Mapping the supply of water requires models and indicators that estimate the volume of water yield available for consumptive uses in a spatial unit such as a river basin. The models and indicators available range from simple basin-scale water balance functions that link precipitation, actual and potential evapotranspiration, land cover and soil water holding properties (Zhang et al., 2001), to complex, spatially-explicit process-based hydrological models that simulate daily runoff calibrated using long-term daily precipitation and stream gauge data (CSIRO, 2008). Additionally, water storage potential and water extraction have also been estimated in more complex models of the water supply ecosystem service (Mendoza et al., 2011). The simple basin-scale models are most suitable when detailed biophysical (climate, soil and hydrological) and land cover data are limited. However, high spatial and temporal resolution outputs will only be possible in well-studied basins with a wealth of spatially-explicit data. The most robust approach to modelling and mapping the flow and availability of water is the application of daily rainfall-runoff models although this approach is very rare in the ecosystem service mapping literature.

2.3.1.3. Raw materials. Modelling and mapping the raw material ecosystem services usually involves estimating spatially-explicit volumes of timber and non-timber (e.g. latex, gums, oils, tannins, dyes etc.) products or volumes of shrub land fuel wood or wetland reeds. At the most basic level, mapping studies have used spatially explicit data of timber harvest volumes (Maes et al., 2012b). This type of data may be relatively easy to acquire from public or private forestry agencies with exclusive property rights over forest resources. Harvest volumes will be more difficult to acquire, or they will be non-existent in locations where property rights over timber resources are poorly defined and implemented. More complex models have been used to map the spatially explicit extraction of timber and non-timber forest products by linking household demographic and labour data with location attributes and forest types to estimate the level of harvest by regions/communities dependent on forest resources for their livelihoods (van Jaarsveld et al., 2005). The complex models are more often applied when property rights are absent or poorly defined such as in less-developed countries.

2.3.1.4. Genetic, medicinal and ornamental resources. While there is clear recognition of the importance of biotic material for the supply of genetic, medicinal and ornamental goods (de Groot et al., 2002), we could only find two examples where medicinal plants have been mapped, (Chen et al., 2009, Fisher et al., 2011) based on land cover data across relatively small geographic areas, although several studies have included genetic or medicinal resources in their assessments based on other variables (Costanza et al., 1997; Vihervaara et al., 2010).

2.3.2. Regulating services

2.3.2.1. Air quality regulation. Modelling air quality regulation is relatively common (e.g. with process-based physical models) but our review showed that the mapping of this service is rare. Modelling tends to be limited to estimates of air pollution removal by urban trees using functions that relate tree cover, leaf area index, weather data, deposition velocity and pollutant concentrations (Jim and Chen, 2008; Escobedo and Nowak, 2009; Maes et al., 2012b; Petz and van Oudenhoven, 2012). Presumably mapping can be difficult because of the high spatial uncertainty; lack of quantitative information about the role of land cover in pollution removal; or the very local character of the service.

2.3.2.2. Climate regulation. Modelling and mapping climate regulation ecosystem services typically relies on proxies because climate regulation is not expressed in climate variables, but in factors explaining climate variations. Temperature anomalies were estimated only in very local studies, for example climate regulation by vegetation in the urban environment (Bastian et al., 2012b). The most common and simplest approach to modelling and mapping respective proxies is to quantify the terrestrial carbon stocks in the soil and vegetation system. More sophisticated models estimate the flows in carbon, or changes in carbon stocks, following a change in land use or land management. Other greenhouse gasses, such as nitrogen, were also modelled and mapped but these studies are rarer. Process models are used to quantify this service more than for any other ecosystem service.

At the simplest level, established relationships between land cover types and carbon stocks are used to approximate total carbon in the land system (Egoh et al., 2008; Nelson et al., 2009). The relationships are calibrated using field measurements of total carbon under different land covers (e.g. tropical forest, open woodland, grassland) and across different pools (e.g. above and below ground biomass, soil, detritus). More complex models simulate the annual change in carbon stocks (i.e. flows) given empirically-derived relationships between climate, soil and vegetation growth. These data-intensive process-based simulation models can be used to estimate with relative precision the flows in carbon following a change in land cover, such as converting an annual cropping system to a permanent tree cover (Crossman et al., 2011c), or change in land management, such as maintaining stubble in a cropping system (Lal, 2004; Liu et al., 2009).

An alternative approach to mapping the flows of terrestrial carbon is to use a remotely-sensed estimate of Net Primary Productivity (NPP). This proxy technique has been used on occasions to map changes in carbon stocks (Raudsepp-Hearne et al., 2010). However, NPP can only be used to map the above and below ground biomass and only measures the net carbon balance (incoming less outgoing).

2.3.2.3. Moderation of extreme events. Moderation of extreme events is usually estimated by modelling the ability of different types of land cover/land use to reduce the risk of inland flooding. The premise is that vegetation and soil retains water as it flows through the landscape, and wetlands and floodplains alter inflow-discharge relationships of watercourses, thereby delaying the time to reach a flood peak. The simpler and most common efforts to model and map flood moderation typically use proxies to estimate water retention capacities, calculated as function of perennial vegetation cover and soil type (Chan et al., 2006; Ming et al., 2007; Schulp et al., 2012). More complex proxy methods can be used to predict the magnitude of floods, given information on simple hydrology (runoff), topography, geology, soil, vegetation and management practices (Posthumus et al., 2010; Ennaanay et al., 2011; Nedkov and Burkhard, 2012). Coral reefs and mangroves also moderate extreme events by buffering waves and tsunamis to the benefit of coastal areas. Several studies map the extent of these two systems as a proxy for the supply of this ecosystem service (Costanza et al., 2008).

2.3.2.4. Regulation of water flows. This service deals with the influence of natural freshwater systems on the regulation of hydrological flows. Services provided include the maintenance of natural irrigation and drainage, and buffering of extreme river discharges and regulation of channel flows (de Groot et al., 2002). Like methods for the moderation of flooding described above, the regulation of water flows is commonly modelled and mapped using hydrological models with soil, vegetation, land use and land cover, topography and precipitation as the major data inputs (Guo et al., 2001; Crossman et al., 2010; Crossman et al., 2011b; Laterra et al., 2012). What is analysed tends to be predominantly ecosystem functions rather than services. In one study, riparian habitats and land use were mapped to determine the impacts of different land uses on the ability of the riparian zone to provide water flow regulation services (Pert et al., 2010).

2.3.2.5. Waste treatment. The mapping and modelling of waste treatment typically involves estimating the capacity of vegetation and upstream freshwater systems to retain nutrients and broader sediments from agriculture (Raudsepp-Hearne et al., 2010; Bai et al., 2011; Simonit and Perrings, 2011). The contribution of nutrients to floodplain and wetland ecosystems from adjacent agricultural land has also been mapped (Posthumus et al., 2010). These analyses typically use soil erosion models such as the Universal Soil Loss Equation (Conte et al., 2011) to estimate sediment transport, but more complex models that involve many indicators of hydrology, agricultural inputs and crop productivity, topography, soil type and land cover have also been used (Simonit and Perrings, 2011).

Other modelling and mapping efforts for the waste treatment ecosystem service have aimed to map the ability of ecosystems to assimilate human excrement (Jansson et al., 1998) or non-human excrement (Bryan and Kandulu, 2009). However, these studies tend to be quite rare, even though they follow more precisely the definition of waste treatment ecosystem services according to de Groot et al. (2002).

2.3.2.6. Erosion prevention. Erosion prevention is a commonly modelled and mapped ecosystem service and uses methods very similar to those used in mapping nutrient and sediment retention under the waste treatment ecosystem service. The erosion prevention service aims to estimate the ability of a landscape or catchment unit to retain soil and is typically calculated as a function of vegetation cover, topography and soil erodibility and the Universal Soil Loss Equation is most often used. Many studies of modelling and mapping erosion prevention exist, for example Gascoigne et al. (2011), Egoh et al. (2008), Conte et al. (2011), and Nelson et al. (2009). From our review we observe that proxy land cover data more commonly used, as compared to specific models of soil erosion.

2.3.2.7. Maintenance of soil fertility. The few existing studies on mapping and modelling of the maintenance of soil fertility use existing soil databases and/or land cover data as proxies for soil fertility or soil productivity (Maes et al., 2012b). For example, Egoh et al. (2008) mapped soil depth and litter cover as proxies for soil organic content, an indicator of soil fertility. Sandhu et al. (2008) is the only study that we are aware of that collected primary data on soil fertility in agricultural soils. Sandhu et al. (2008) estimated the quantity of fertile soil formed annually by measuring earthworm populations. They also estimated the mineralisation of plant nutrients through direct measurement of nitrogen to organic matter ratios in the soil.

2.3.2.8. Pollination. The processes underpinning the pollination ecosystem service and its relative importance to humans has been well documented (Kremen et al., 2002, 2004) but the service is not often mapped due most likely to the relatively small scale of the process. Proxy methods using land cover and land use, pollinator habitat and crop yields are the most common approaches to map the pollination service (Chan et al., 2006; Lautenbach et al., 2011; Petz and van Oudenhoven, 2012; Schulp et al., 2012). The most complex example of modelling and mapping the pollination ecosystem service is that of Lonsdorf et al. (2011), who use a mix of 23 land uses, crop yields, pollinator habitats and abundances, climate and distance proxy measures.

2.3.2.9. Biological control. In our review, we could only find one example where the biological control service was mapped using primary data of pest density (Sandhu et al., 2008). Proxy data has been used, for example Brenner et al. (2010) used land cover and Petz and van Oudenhoven (2012) used tree density.

2.3.3. Habitat services

2.3.3.1. Life cycle maintenance. Life cycle maintenance ecosystem services are, according to TEEB (2010), the attributes of the biotic and abiotic environment that support life cycles of species. This ecosystem service is one of, if not *the* service most dependent on well-functioning and biologically diverse ecosystems. Following this statement, models and maps of the life cycle maintenance ecosystem service typically estimate habitat suitability for a species and/or biodiversity based on species distributions and a number of independent variables that control species distribution. There are a wealth of studies modelling habitat suitability of species driven by the need to better understand what constrains species and how those constraints may change in response to changes in habitat and climate (Crossman and Bass, 2008; Crossman et al., 2011a, 2012a; Summers et al., 2012). The methodology has a long pedigree in the ecological and conservation planning sciences, but is not common in the ecosystem services literature, although a number of good examples do exist (Nelson et al., 2009, Rolf et al., 2012). Data inputs to habitat suitability models typically include species distributions, soil characteristics, topographic and climatic variables and land use and land cover. The broader habitat suitability modelling includes a wide array of approaches, from complex statistical models to more simple composite indicators (Guisan and Zimmermann, 2000). In the ecosystem services literature, the simpler indices of species distribution and biodiversity hotspots tend to be more often used (Willemen et al., 2008, Posthumus et al., 2010).

2.3.3.2. Maintenance of genetic diversity. Both TEEB (2010) and de Groot et al. (2002) (although the service is called 'refugium function' in the latter) define the maintenance of genetic diversity service in as being provided most prominently where there is high species endemism, i.e. in biodiversity hotspots. Mapping of biodiversity hotspots has a relatively long history in the conservation planning and management sciences (Myers et al., 2000) and is present more broadly in the ecosystem services literature. Yet, we did not identify any study explicitly mapping the maintenance of genetic diversity. The life cycle maintenance ecosystem service above reviews the methods used to map and model biodiversity and species habitat.

2.3.4. Cultural and amenity services

2.3.4.1. Aesthetic information. The aesthetic information ecosystem service is defined as the pleasure people receive from scenic beauty provided by natural areas and landscapes (TEEB, 2010). The modelling and mapping of this is commonly done through questionnaires or interviews on personal preferences, or through mapping landscape attractiveness based on factors such as naturalness, skyline disturbance or viewshed (de Vries et al., 2007). Another common method is the identification of real estate adjacent to or in the vicinity of natural areas because the end goal is to calculate the marginal price people are willing to pay for a property with a view (Grêt-Regamey et al., 2008a, Crossman et al., 2010) or in a favoured holiday location (Raudsepp-Hearne et al., 2010). Data used to model and map this typically involve distance metrics of real estate sales and locations in relation to important natural features or other landscape characteristics.

2.3.4.2. Opportunities for recreation and tourism. The recreation and tourism ecosystem services are the most commonly mapped from the broad grouping of cultural services because they are relatively simple to quantify and there are many methods for calculating their value. The methods are many and varied but often involve very location-specific proxies for recreation/tourism such as the number of waterfowl or deer hunting kills (Jenkins et al., 2010; Raudsepp-Hearne et al., 2010; Naidoo et al., 2011), total fish catch per unit area (Lara et al., 2009), number of cyclists (Willemen et al., 2008), landscape naturalness and attractiveness (Maes et al., 2012b; Schulp et al., 2012), number of walkers (Petz and van Oudenhoven, 2012) and daily or overnight stays at tourist locations (Grêt-Regamey et al., 2008b; Anderson et al., 2009; Eigenbrod et al., 2009). Accessibility and land cover are important components of models that measure this service.

2.3.4.3. Inspiration for culture, art and design. The few examples of this ecosystem service we found in our review have focused mainly on cultural heritage values, expressed often in qualitative terms (Bryan et al., 2010, Posthumus et al., 2010). Land use and land cover are the prime input data (Willemen et al., 2008, Brenner et al., 2010).

2.3.4.4. Spiritual experience. There have been a small number of studies which have aimed to map the sense of place and broader social values of landscapes, which arguably includes spiritual experience. The most pronounced of these mapping studies include Raymond et al. (2009), Bryan et al. (2010, 2011b) who captured the spatially explicit locations considered by local people to have high importance for social and spiritual value.

2.3.4.5. Information for cognitive development. No mapped examples were found.

3. The blueprint

Given the many and varied approaches for modelling and mapping ecosystem services, we argue there is a need for a standard process for documenting respective studies. Here we present a blueprint that records a set of standard attributes for mapping and modelling studies. To develop the blueprint, several members of the Ecosystem Services Partnership (ESP) Thematic Working Group on Mapping Ecosystem Services[7] convened a working group session at the 5th ESP Conference 2012 in Portland, Oregon, USA. Held across 2 days at the conference, our 'Mapping and Modelling Ecosystem Services Working Group' aimed to develop and discuss the blueprint and then validate this blueprint with real examples of mapping and modelling studies supplied by the working group participants. During the working group session, the participants revised our early draft blueprint and discussed the suitability and applicability of each attribute. At the end of the first day we arrived at a blueprint template for documenting mapping and modelling studies of ecosystem services (Fig. 1).

The blueprint consists of two parts: (i) a preamble section that contains meta-information about the individual mapping/modelling study (Fig. 1a), and (ii) the main blueprint table that contains attributes for each ecosystem service mapped and modelled in the study described under the preamble (Fig. 1b). The purpose of the preamble is to collect the necessary "why, where, when and who?" data that provides the broader context for the study as well as contact details of the person who conducted the study which can be used for follow up or clarification.

The main blueprint table (Fig. 1b) contains eight major attributes plus a comment box. Three of the attributes have sub-components. The attributes are designed to be simple but capture all the major elements of ecosystem service mapping and modelling studies. The first attribute, mapped ecosystem service' is open to any ecosystem service type although we recommend following the classification system of TEEB (2010) or the Common International Classification of Ecosystem Services system currently under development[8] . The accounting definitions attribute calls for the type of ecosystem service (for example whether it is a stock of natural capital, and underpinning ecosystem function or process, or a flow of a final ecosystem service; see Box 1) and the beneficiary of the ecosystem service, i.e. whether it is supply or demand or a benefiting or providing area. The indicator attribute asks for a short name or description of the main indicator used to map the ecosystem service, such as surface water extraction (water), timber production (raw materials), carbon sequestration (climate regulation), soil organic carbon (maintenance of soil fertility), or overnight visitors (tourism). The next attribute asks for the three major elements used to spatially and temporally quantify the indicator.

The next three attributes ask for information on the underlying model and data used to map the ecosystem service. Firstly, qualitative information on the source of the data is requested, followed by the method by which the indicator was modelled, and then the description of the spatial details of the map and/or underlying data (scale, extent and resolution). Information provided for these three attributes will be highly variable depending on the ecosystem service mapped and the scale at which it is mapped. For example, carbon sequestration may be modelled at a local scale (e.g. 10 km^2) using a high-resolution (e.g. 1 ha) process model whereas at a global scale carbon sequestration may estimate using aggregate statistics or primary remotely sensed data at coarse resolution (e.g. 5 km^2). The next attribute calls for the timeframe of the mapped or modelled data, i.e. whether the data is for a single year or over a period of years.

The final two attributes ask the person completing the blueprint to provide a self-assessment of the mapping and modelling study. The first attribute of this group asks the person to assess on a 5-point Likert scale whether the objective of the study met (yes=1; no=5), and then to provide some comment on that self-assessment, such as whether there are some key assumptions underlying the model and data, limitations of the data, data gaps etc. The information provided in the comment attribute should be sufficient for a reader to understand the uncertainties and risks associated with modelling and mapping the particular ecosystem service. The reader can then build on the previous attempts at modelling and mapping the ecosystem service as documented in the blueprint. If the reader is only using existing mapped information they can use the information in the comments attribute to decide whether the data would be valuable to use in their decision making.

4. Worked example

Participants of the *Mapping and Modelling Ecosystem Services Working Group* session each completed a blueprint for their studies. We collected a total of 13 completed blueprints and have selected one to showcase here as an example (see Online Supplementary Appendix 2). Our example demonstrates the type of information that can be included, ranging from the short succinct quantitative responses, to the longer, qualitative descriptions. The mix of data types and the depth of information provide a valuable resource which could be incorporated into an online database that could in future inform people wanting to map ecosystem services in and around New York City in the USA, or map similar ecosystem services in urban and peri-urban environments.

5. Discussion and conclusion

The primary purpose of this blueprint is to provide a template and checklist of information needed for those carrying out a modelling and mapping ecosystem service study. A secondary purpose is to provide, over time, a database of completed blueprints that becomes a valuable information resource of methods

[7] 〈http://www.es-partnership.org/esp/79222/5/0/50〉
[8] 〈http://cices.eu/〉

a

1. Name of the mapping study:		**2.Purpose of the study:** (e.g. biodiversity conservation, awareness/communication, scenario/trend analysis, valuation, mapping, ex-ante decision support, regulating/monitoring policy, methodology development)	
3. Location of the study site(s) and biophysical type: (e.g. watershed name, biome)		**4. Study duration** (e.g. 2000-2005)	
5. Administrative unit: (e.g. city, state, country, continent)		**6. Main investigators** (e.g. name and affiliation)	
7. References (e.g. publications, project website)		**8. Type of project** (e.g. research, outreach, education)	
9. Funding source:		**10. Contact details:**	

b

Mapped ecosystem service		**Accounting definitions**		**ES Indicator**	**Quantification unit**			**Input data source**	**Quantification method**	**Spatial details**			**Mapped year or period**	**Study objective met**	**Comments**
		Type (e.g. stock, flow, process, function)	**Beneficiary** (e.g. supply, demand, benefiting/ providing area)		**Quantity** (e.g. kg)	**Area** (e.g. ha or watershed)	**Time** (e.g. year)	(model output, measured/primary, aggregated statistics)	(process, empirical, participatory + name of model)	**Scale** (global, national, regional, local)	**Extent** (size)	**Resolution** (pixel size, minimal mapping unit)	(e.g. 2000 or 1990 - 2050)	(1 = yes; to 5= no)	(e.g limitations, key assumptions)
Provisioning	Food														
	Water														
	--														
	Other														
Regulating	Air quality														
	Climate														
	--														
	Other														
Other															

Fig. 1. (a) Preamble of the blueprint template for reporting ecosystem service mapping studies and (b) blueprint template for reporting ecosystem service mapping and modelling studies.

and information used in previous modelling and mapping studies. The blueprint database would complement other ecosystem services databases such as the Ecosystem Services Value Database (ESVD) (de Groot et al., 2012) and the Environmental Valuation Reference Inventory[9] . The blueprint database would be of potential value to researchers starting a new mapping study and to practitioners and policy makers searching for ecosystem service information to use in decision-making. While we recognise that every new study will require its own unique approach to modelling and mapping, we suggest that this blueprint and a rich open-access blueprint database will establish a set of standard attributes that provides increased certainty about mapped ecosystem services.

Initiatives such as the Experimental Ecosystem Accounts under the framework of the United Nations System of Environmental Economic Accounts (United Nations Statistical Division, 2012), the World Bank's Global Partnership for Wealth Accounting and Valuation of Ecosystem Services (WAVES)[10] and the GEF-funded Project for Ecosystem Services[11] aim to get ecosystem service values into mainstream national accounting. Other recent global developments such as the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES)[12] and the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011–2020[13] aim to recognise, protect and enhance the values provided to society by biodiversity and ecosystem services. Other initiatives related to the private sector, such as the Ecosystems Work Program of the World Business Council for Sustainable Development[14] or related to particular natural resource sectors, such as the International Water Management Institute's ecosystems and water security research topic (Boelee, 2011)[15] aim to get ecosystem services into their constituents' decision making. There is also a growth in the commodification and trade in natural capital and ecosystem services. The Ecosystem Marketplace[16] provides a detailed information and follows the various trading markets of water, carbon and biodiversity, and payments for ecosystem services programs are becoming more common (Wunder et al., 2008; Gómez-Baggethun and Ruiz-Pérez, 2011). Complementing these global developments are many continental- (Maes et al., 2012a), national- (UK National Ecosystem Assessment, 2011; Pittock et al., 2012) and regional-scale (Maynard et al., 2010) programs and initiatives.

[9] 〈https://www.evri.ca/〉
[10] 〈http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/0,,contentMDK:23124612~pagePK:148956~piPK:216618~theSitePK:244381,00.html〉
[11] 〈http://www.proecoserv.org/〉
[12] 〈http://www.ipbes.net/〉
[13] 〈http://www.cbd.int/sp/〉
[14] 〈http://www.wbcsd.org/work-program/ecosystems.aspx〉
[15] 〈http://www.iwmi.cgiar.org/Topics/Ecosystems/index.aspx〉
[16] 〈http://www.ecosystemmarketplace.com/〉

This growth in policy attention toward ecosystem services, demands increased knowledge, rigour, transparency and certainty in accounting, modelling, mapping and valuing methods so that ecosystem services can become mainstream. We argue that there should be effort directed towards development of standards and protocols for modelling and mapping ecosystem services to deal with this policy challenge and remove the uncertainty that relates the many and varied approaches used to date, especially if ecosystem services are to be included in national accounting as well as private and public sector invest decision making, and are to become commonplace in financial markets. We found that being aware of the current knowledge gaps in ecosystem service mapping is important for developing policies for biodiversity and ecosystem services preservation, such as those related to accounting and valuation of ecosystem services or to ecosystem service markets. In this sense, a greater effort is needed to map cultural ecosystem services, and invest in mapping programs that include more than one service to be able to analyse trade-offs among services. There is also a need to shift effort to regions where ecosystem services are relatively poorly mapped such as in South and Central America.

While any study that models and maps ecosystem services will have its unique characteristics and will be largely driven by data and model availability, a tool such as the blueprint presented here will reduce the uncertainty associated with quantifying ecosystem services and thereby help to close the gap between theory and practice, e.g. the implementation gap (Cook and Spray, 2012). The next steps are to further refine the blueprint, distribute among the ecosystem service community and then develop an open access database to store and retrieve completed blueprints. The Ecosystem Services Partnership[17] (ESP) as an international network organisation seeks to integrate ecosystem services science and policy community and aims to enhance and encourage a diversity of approaches while reducing unnecessary duplication of effort in the conceptualization and application of ecosystem services (Burkhard et al., 2012a). The ESP helps to increase the effectiveness of ecosystem services science, policy, and applications and is therefore the ideal avenue for developing ecosystem service mapping and modelling guidelines, like the blueprint presented here.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ecoser.2013.02.001.

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[17] 〈www.es-partnership.org〉

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