Methodological interlinkages for mapping ecosystem services - from data to analysis and decision-support

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Abstract

A broad array of methods have been developed and applied to map ecosystem services and their values at various geographic scales. For example, the ESMERALDA project developed methods for ecosystem service mapping across Europe. This paper describes how different methodological interlinkages can be used in ecosystem service mapping and assessment and how the integration of information can be facilitated to assist in decision-making processes related to sustainable use and protection of ecosystem services. This paper is based on a literature review and expert consultations throughout the project. The accumulation of knowledge in ecosystem assessment processes will be described through multiple steps: 1) data compilation, 2) analyses run via independent or linked methods applications and tools, 3) integration of information from multiple analyses and 4) finally, feeding into the decision-support frameworks. The challenges and possibilities of using combinations of various datasets and methods will be discussed. This workflow is demonstrated with real-world applications. In addition, technical pitfalls and challenges, as well as linkages to overall ecosystem assessments and policy questions, are analysed and discussed.

Keywords

biodiversity, ecosystem services, mapping, ESMERALDA, MAES, Europe

Introduction

Harmonising the broad array of methods for mapping and assessing ecosystem services (ES) has been recognised as an important step in delivering quantitative and comprehensive information on the status and trends of ecosystems and their services. This is particularly important in regional scale assessments such as the MAES*[1] work for the European Union (Maes et al. 2012, Vihervaara et al. 2015, Burkhard and al. 2018) and IPBES regional ecosystem assessments (www.ipbes.org; IPBES 2015,IPBES 2016). A transparent and harmonised methodology is a prerequisite for producing a comparable and comprehensive picture on ecosystems and the services they deliver to support decision-making processes. The field of ES research has matured during the past 20 years (Costanza et al. 1997, Costanza et al. 2017, Seppelt et al. 2013, Vihervaara et al. 2010, Seppelt et al. 2013) and attempts to harmonise ES classification and indicators have been made (Feld et al. 2009Feld et al. 2009,Mononen et al. 2016). Meanwhile, tens or even hundreds of biophysical, social and economic quantification and mapping methods have been developed and applied in ecosystem assessments (Lavorel et al. 2014, Santos-Martín et al. 2018, Vihervaara et al. 2018, Dunford and al. 2017).

Burkhard et al. 2018 have proposed an operational framework for an integrated ecosystem assessment that is composed of nine consecutive steps; the focus of this paper is primarily on steps 5-7, i.e. selecting indicators and quantifying and mapping ecosystem condition and ES. The workflow described in our paper follows the principles of the operational framework for integrated assessment, but places special emphasis on method interlinkages and information integration.

An initial and non-trivial challenge in linking methods is the diverse terminology that is used to describe and define methods. The terminology that has been used in previous ES classifications, literature and ecosystem assessment processes is far from consistent and multiple terms are often conflated. For example, in the literature review conducted by the ESMERALDA project, there is mixed use of terms such as datasets, indicators, indexes, methods, models, tools for quantification mapping, assessment and decision-support (Santos-Martín et al. 2018). In a broad sense, all these terms have been used to mean "methods" in general, even though they represent different concepts and define very different aspects of ecosystem assessment processes. Difficulties with categorising tools were also noted in a review of 68 decision-support tools (Grêt-Regamey et al. 2017). The challenge of establishing common terminology increases when combining methods from multiple disciplines since biophysical, social and economic sciences have their own common understanding and usage of specific terms. A further challenge arises when methods are classified by the ecosystem functions or services to which they are applied, in addition to their technical characteristics (e.g., models for carbon stocks and sequestration, models for hydrology, models for biological interactions etc.)(Vihervaara et al. 2018).

For the ESMERALDA project, a comprehensive glossary of terms was produced by Potschin-Young et al. 2018a Potschin-Young et al. 2018b. They define "methodology" as "the particular chain of methods, data and other relevant resources (e.g. stakeholders) that are involved in solving a specific problem", "method" as "a reproducible process relying on specific types of inputs for achieving a specific goal" and "model" as "a simplified representation of a complex system or process including elements that are considered to be essential parts of what is represented". In this paper, "methodology" is a chain of methods and models are a broad type or grouping of methods. The term "methods" is commonly used throughout the text and it also includes models. However, in some parts, models may be referred to as certain types of methods.

In this article, we emphasise the *technical* classification (i.e. focusing on methods, opposite to *thematic* classification related to, for instance, particular ecosystem type or ecosystem service) of individual biophysical, social and economic methods that can be applied to one or more ecosystem services. We have reviewed the definitions of ES quantification models and methods used in previous projects, such as OPERAs and OpenNESS and the literature on mapping and assessing ecosystem services. In addition, experts attending the ESMERALDA workshops (approximately 50 persons per workshop) have been consulted to obtain a comprehensive overview of available methods and their views on the classification of methods described in this paper.

The aims of this paper are:

1. to develop a structured workflow for integrating multiple methods for mapping and assessing ecosystem services and
2. to demonstrate such a workflow through examples of how information from various method classes can be integrated.

The workflow for mapping and assessment of ecosystems and their services

The materials for this paper are based on findings of the synthesis reports on social (Santos-Martín 2018), economic (Brander et al. 2018) and biophysical (Vihervaara et al. 2018) mapping and assessment methods, the integration report of those methods (Santos-Martin et al. 2018) and a database of existing studies (Santos-Martín et al. 2018). A literature review, based on the ESMERALDA methods database (Santos-Martín et al. 2018), was initially used to identify mapping and assessment methods. This initial process yielded a wide variety of datasets, indicators, models, software tools, decision-support tools etc. that have been described in literature as "methods". We then organised them into the different categories and methods classes that are presented in the deliverables 3.1 (Santos-Martín 2018), 3.2 (Brander et al. 2018) and 3.3 (Vihervaara et al. 2018) of ESMERALDA.

The various terms used to describe the process of mapping and assessing ecosystems and their services were refined towards more of a structured scheme (Fig. 1), which is explained and elaborated in this paper. In the early phases of developing this structured scheme, it became apparent that there are multiple terms and concepts that researchers, who came from different disciplines, are using and interpreting differently. For instance, the term modelling could refer to the functional representation of ecosystem processes, assessment of economic scenarios or the calculation of uncertainties with Bayesian belief networks for decision support, all of which are positioned quite differently in the ecosystem assessment process. Initially, we divided the identified methods applied within a workflow under three main categories: I) Selecting the assessment target, II) Data & mapping, divided further into Direct and Indirect Measurements and Modelling and III) Decision-support framework. Within those main categories, terms were grouped in more detailed classes.

Selecting the assessment targets

The process of mapping ES and their values falls within the broader process of ecosystem service assessment. The term "assessment" is defined as "the analysis and review of information derived from research for the purpose of helping someone in a position of responsibility to evaluate possible actions or think about a problem" (Potschin-Young et al. 2018a). In the beginning of the assessment process, it is important to define what is the system, problem or environmental challenge to be assessed, who are the relevant stakeholders, what is the spatial and temporal scale of the assessment and to identify alternative options or scenarios that need to be compared, for instance, climate change or land use change. It is also important to recognise the end users of the assessment results where the type of output (e.g. spatial maps) would have a significant impact on the interpretation and implementation of the results.

Ecosystem assessments have been compiled for various policy processes, such as measuring and reporting indicators for the UN Sustainable Development Goals (SDG), Aichi Targets of the Convention on Biological Diversity (CBD) or, recently, for regional ecosystem assessments of IPBES. Earlier assessment processes related to ES have been, for instance, the Millennium Ecosystem Assessment 2005 and the Economics of Ecosystems and Biodiversity (TEEB) assessments (www.teebweb.org). The questions driving implementation of the MAES work in EU Biodiversity Strategy have been divided into five categories: knowledge requests, policy support questions, questions on resources and responsibilities, application questions and technical and methodological guidance questions (Maes et al. 2018).

ES assessment is arguably the most useful form of assessment to guide development towards sustainable social-ecological systems. This recognition is at the core of the ESMERALDA project and MAES work of the EU. The EU Biodiversity Strategy Action 5 sets the requirement for an EU-wide knowledge base designed to be: a primary data source for developing Europe's green infrastructure; a resource to identify areas for ecosystem restoration; and, a baseline against which the goal of 'no net loss of biodiversity and ecosystem services' can be evaluated. In addition to these aims, there are also other valid assessment purposes, for instance, related to environmental impact assessments or integrated natural capital accounting (Hein et al. 2016). It is worth highlighting that the need for spatially-explicit ES data and improved national environmental statistics is also leading to the development of natural capital accounting (e.g. KIP-INCA process at EU), which implements the system of environmental-economic accounting and experimental ecosystem accounting (UN SEEA-EEA). The implementation of ecosystem accounting can usefully build on data and knowledge, based on indicators and mapping methods (see Lai et al. 2018).

For ecosystem service assessments, the distinction between capacities (potential supply) and flow (determined by demand) is particularly important (Burkhard et al. 2012, Castro et al. 2014, Martínez-Harms and Balvanera 2012). Without this distinction between potential and actual ES, mapping and assessment results may not have significance for decision-support processes. For the next steps of the workflow, we focus on those steps that are relevant to ecosystem assessment in the context of the MAES process.

Compiling the data and selecting the indicators

Quantification of ES in biophysical terms is a prerequisite for their social and economic evaluation and subsequent integration of this information into decision-making processes (Vihervaara et al. 2017; Fig. 2).

In the ESMERALDA project, biophysical methods are classified in three major groups: direct methods, indirect methods and modeling methods. Direct measurement methods are the measurements of a state, a quantity or a process from ecosystem observations, monitoring, surveys, questionnaires or data from remote sensing and earth observations, which cover the entire study area in a representative manner. Direct measurements deliver a biophysical value of ES in physical units which correspond to the units of the indicator and quantify or measure a stock or a flow value. Direct measurements can be used as primary data inputs to other methods or used directly as ES indicators. The use of direct measurements, however, are often impractical and prohibitively expensive beyond the site level and, therefore, are usually used as an input into a biophysical mapping method or to validate certain mapping and assessment elements. In some cases, direct measurements are simply not available for all ES.

Indirect measurement methods rely on the use of different data sources that provide biophysical values in physical units but process this information through further interpretation or classification. They can be based on remote sensing and Earth observation derivatives such as land cover, normalised difference vegetation index (NDVI), surface temperature, soil moisture etc. which are extracted from the original sources using specific procedures. For example, land cover can be derived from remote sensing images by visual interpretation or automated classification; and NDVI is derived by measuring the difference in solar radiance absorption and re-emittance of vegetation using particular spectral bands.

Use of indicators is common in ecosystem assessments and there is extensive literature which discusses them (e.g. Feld et al. 2009, Müller and Burkhard 2012, Mononen et al. 2016). Indicators, as quantifiable metrics, can directly reflect the status of ES (scientific indicator) or be more tailored to measure, for instance, effectiveness of policy actions to protect ecosystems (policy indicators) (Maes et al. 2014, Potschin-Young et al. 2018a. Indices are a specific type of scientific indicator. Often indices are end-products of sophisticated calculations in a case study and, thus, their applicability in different circumstances can be limited. Sometimes, indices are a composite of indicators, consisting of multiple abiotic and/or biotic characteristics (Kettunen et al. 2012).

Reviewing, acquiring and compiling the required spatial data is one of the most important and, at the same time, challenging and laborious task as data are usually dispersed across various sources and/or may need to be pre-processed to be suitable for analyses, which can be very time consuming. There are many factors affecting the availability of data in different countries, such as level of economic development, funding or technological capabilities. As a result, harmonised datasets covering a large area can be difficult to find. Still, the development of technology applicable at the global scale has allowed for more opportunities to produce consistent, detailed and accurate data. Sometimes, the data must be purchased from the data producer but many existing datasets are freely available. A preliminary study on spatial data and analytical methods for assessing the ecosystem services and connectivity of the protected areas network of the Green Belt of Fennoscandia, i.e. a chain of protected areas on the borders of Russia, Finland and Norway, resulted in a list of 108 potential datasets across the study area varying from regional to global scales. Of the datasets reviewed, only eight were commercially available, while others were freely available or through co-operation (Itkonen et al. 2014).

Quantifying and mapping ecosystem services

Building from previous experiences

Dunford and al. 2017 illustrate where and in what contexts, different methodological combinations are used and provide suggestions for those working in ecosystem service assessment drawn from the experiences of 27 case studies. The findings of the OpenNESS case study experiences stress that methodological plurality, flexibility and creativity are key, if case studies are to best address practical local to regional problems. Another EU project, OPERAs, used five classes to group biophysical models which we also considered very useful core classes in our work (Lavorel et al. 2014).

Biophysical methods

Biophysical methods include direct and indirect measurement methods and modelling. The modelling includes several groups of approaches that come from ecology or other earth sciences fields such as hydrology, climatology, soil science etc. The biophysical model groups described in ESMERALDA are: phenomenological models, macro-ecological models, trait-based models, process-based models, statistical models, ecological connectivity models and state and transition models (see Table 1). Detailed descriptions of the biophysical models can be found in Vihervaara et al. 2018.

Social methods

Social methods for mapping and assessing ES measure individual and collective preferences in order to support the implementation and further development of the ecosystem service concept. By definition, social methods involve people in the assessment process. In ESMERALDA, social methods were divided into three main categories in relation to how stakeholder are engaged. Observation methods require multiple data as they are quantitative methods and are usually developed in collaboration with researchers (i.e. preference assessment, time-use and photo-elicitation). Some of the social methods could also be used in selecting assessment targets, for instance, by analysing social preferences and associated values of ES. Consultation methods are based on qualitative data that are usually applied in collaboration with non-academic stakeholders (i.e. narratives, Q-methodology). These methods are usually articulated through in-depth and semi-structured interviews that allow research participants to express their motivations and the diverse values of ES through their own stories and direct actions (both verbally and visually). These types of methods are usually applied in order to understand and describe the variety of motivations behind the social value that different stakeholders attribute to nature. Engagement methods are able to gather qualitative and quantitative data by collaborating with researchers and non-academic stakeholders (i.e. Public Participatory GIS, participatory scenario planning and deliberative assessment). These methods are usually articulated through participatory and deliberative tools (focus groups, citizens juries, participatory or rapid rural appraisal (PRA/RRA), Delphi panels etc.). This third group of methods can contribute to solve social conflicts by learning and knowledge co-production, as it fosters discussion between different stakeholder groups regarding trade-offs amongst different ES (deliberative valuation), their spatial distribution (PGIS) and the future trends of ES and their implications for human well-being (participatory scenario planning) (Santos-Martín et al. 2018).

Economic methods

A variety of methods have been developed for estimating the economic value of ES that are designed to span the range of valuation challenges raised by the application of economic analyses to the complexity of the natural environment. Fig. 3 provides a representation of the available economic methods for valuing ESs. A key distinction is between methods that produce new or original information generally using primary data (primary valuation methods) and those that use existing information in new policy contexts (value transfer methods) (Brander et al. 2018).

Integrated modelling frameworks

In addition to the above-mentioned specified method classes, it was observed that there are a number of tools that, although often referred to in literature as “methods”,are actually better described as software tools or platforms that combine multiple individual models (Fig. 1: Mixed methods / tools box). We decided to call this group of tools "Integrated modelling frameworks". Examples of such commonly used platforms are InVEST and ARIES. This group includes tools designed specifically for ecosystem services modelling and mapping that can assess trade-offs and scenarios for multiple services. They integrate various biophysical, but also social and economic, methods to assess and map different ES. The methods are usually organised in modules that are designed for the assessment of a particular ES. Integrated modelling frameworks utilise GIS software as a means to operate with spatial data and to produce maps. They can work as extensions of commercial or open-source software packages, stand-alone tools or web-based applications. They are designed to help researchers in ES assessment and enable decision-makers to assess quantified trade-offs associated with alternative management choices and to identify areas where investment in natural capital can enhance human development and conservation (Vihervaara et al. 2018).

Integrating information from biophysical, social and economic methods

The literature survey clearly shows that, despite the numerous papers published in the separate fields of ES research, i.e. biophysical, social or economic studies alone, studies using multiple methods are still rare (Santos-Martín et al. 2018). Biophysical data are often used as an input for various economic and socio-cultural methods. For instance, if a multi-disciplinary paper uses advanced biophysical methods, the economic methods used in the same study tend to be over simplified – and vice versa (Schägner et al. 2013). There is evidently a need to understand how different method combinations (e.g. complex biophysical together with complex economic, or simple biophysical with complex economic, or simple-simple mix etc.) affect the results and usefulness of mapping and assessment studies. This kind of increased understanding is also a necessity to improve transparency and collaboration between different disciplines dealing with ES research (Vihervaara et al. 2018).

The challenges, related to data availability and quality and selection of the right combination of methods for specific cases, need to be taken into consideration in the early stages of an ecosystem assessment. The availability and accuracy of data may vary between areas, for instance between terrestrial and marine areas, between member states in EU and between provisioning and regulating or cultural ES (cf. Fürst et al. 2017). In many cases identified in the literature review, various data types from different sources were used for analysis: expert scores (Burkhard et al. 2012), direct field or remotely sensed measurements (Mikolajczak et al. 2015) or various combinations of them (Vihervaara et al. 2018). This might have unwanted implications for the results and accuracy of assessments if the data lack spatial and/or temporal consistency and that usually requires covering the whole study area and harmonised data collection times. The scale of the study area determines the required spatial resolution of the data. Data for national or regional assessment as spatially coarse data can be usable whereas, in local studies, more explicit data are needed to reveal the variations inside the system.

Evaluation of the quality and accuracy of the data, methods and models is challenging since mapping and assessment of different ES use different approaches with different data and methods. Complexity in using more than one type of method to quantify and map certain ES might end up with significantly different outcomes. This variation and uncertainty from the different methods should be considered in designing ecosystem assessments (Seppelt et al. 2013). While the importance of considering the uncertainties in the analyses is widely acknowledged, Boerema et al. 2017conclude that uncertainty is often not included and validation is mostly ignored.

Processing integrated information via decision-support frameworks

The integration of results from mapping and assessment applications is essential if we are to make informed decisions regarding ecosystem use and management. We use the term "decision-support frameworks" to describe the set of methods that are designed to structure and integrate information from multiple sources with the purpose of providing information for decision-making. Examples of such methods include Bayesian Belief Networks (BBN), multi-criteria analysis (MCA) and cost-benefit analysis (CBA) (Brander et al. 2018). In previous projects, for instance in OpenNESS (Harrison and Dunford 2015), such methods have been listed as ES assessment methods. In some cases, biophysical methods such as the Zonation programme for prioritising multiple-use landscapes for conservation (Moilanen et al. 2005), could be interpreted as a decision support tool. Clearly visualised outcomes of model integrations, such as ecosystem service trade-offs, can be tailored to support decision-making, for instance, using virtual laboratories (Holmberg et al. 2015). Virtual ES laboratories can be used to either increase knowledge through storylines or they can have user-friendly interfaces to enable decision-makers to combine and explore different data layers by themselves. In the end, the aim of decision-support frameworks is to help organise and communicate information on multiple assessment criteria to assist decision-makers in evaluating the original assessment target.

Conclusions

In this paper, we synthesised and organised the available methods for ecosystem mapping and assessment in a workflow graph that describes the production of information from direct observations and measurements through to various methods to support decision-making. The first step in any ecosystem assessment is to orientate the process to the overal objectives, which can either be the direct aims of assessing the status and trends of ecosystems or be defined by the specific needs of policy processes such as IPBES, CBD or EU Biodiversity Strategy. We identified separate biophysical, social and economic models and methods, integrated modelling frameworks and decision-support frameworks.

The results of mapping and modelling methods can provide quantified spatial data, which can be used directly or through decision-support tools in ecosystem assessments, such as MAES and IPBES. Ecosystem assessments aim tomeasure the status and trends of ecosystems and their services, which implies that such processes need to be repeated at regular intervals of time. This enables us to critically analyse the advantages and challenges of the currently applied methods and how these should be improved for the future assessments. There has been a significant development in the understanding and knowledge of ecosystem services in Europe during the last decade. The ESMERALDA project has provided a flexible methodology for EU member states that helps to set new goals for sustainable management and protection of ES towards the 2030 agenda. Mapping and assessment of ecosystems and their services necessarily require the linking of biophysical, social and economic methods to achieve a holistic understanding of the values and benefits provided by nature. We observed that many existing applications used mis-matched combinations of highly sophisticated biophysical models with over-simplified economic or social methods and vice-versa. Understanding the applicability and restrictions of the output data from the biophysical mapping and assessment is needed if the data are to be used as input for social or economic methods.

Improving guidance on how to optimally link assessment methods is seen as one of the aspects that requires further study and development in the future. In addition, there is a need to better integrate separate information outputs from biophysical, economic and socio-cultural mapping and assessment applications. This is where the combination of complementary pieces of information are used to measure different aspects of an ecosystem service (e.g. sustainability, value and distribution) to support decision-making. The workflow, developed in this paper, can be used to plan for better integration across information sources. We believe that the workflow will help future communication and collaboration between disciplines and contribute to a better understanding of the assessment process by the wide variety of stakeholders involved in ecosystem assessments.

Conflicts of interest

No conflicts of interest.

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Endnotes

*1 http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm

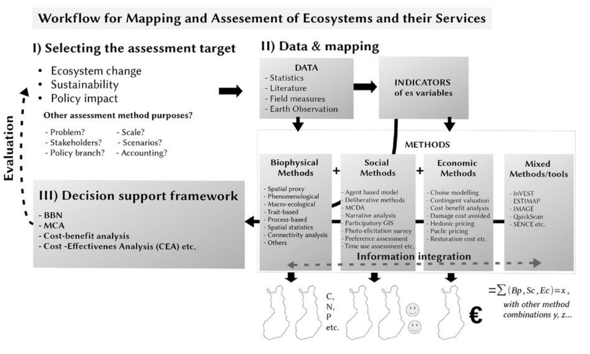

Figure 1.

Framework for mapping and assessment of ES that links multiple methods and integrates multiple types of information. Direct and indirect measurement can produce data that is used to calculate indicators and/or indices (see below). Direct and indirect measurements can either feed in to methods, including single models and integrated modelling frameworks or to decision-support frameworks (directly or via methods). Subsequently, the integrated information can be used for wider ecosystem assessment processes, which can have different aims, for instance, reporting for policy targets or detecting status and trends of ecosystems.

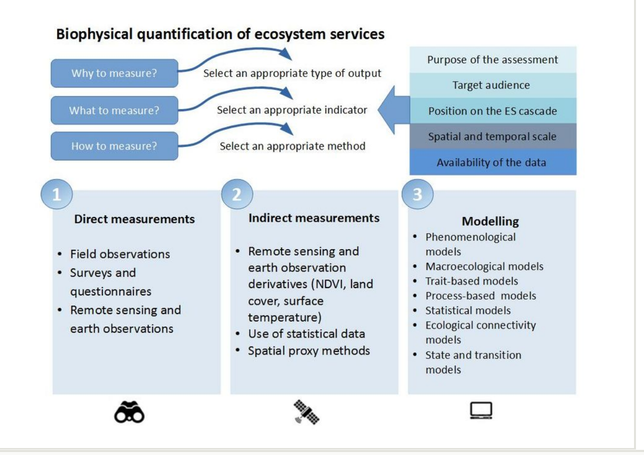

Figure 2.

Classification of biophysical methods (modified from: Vihervaara et al. 2017).

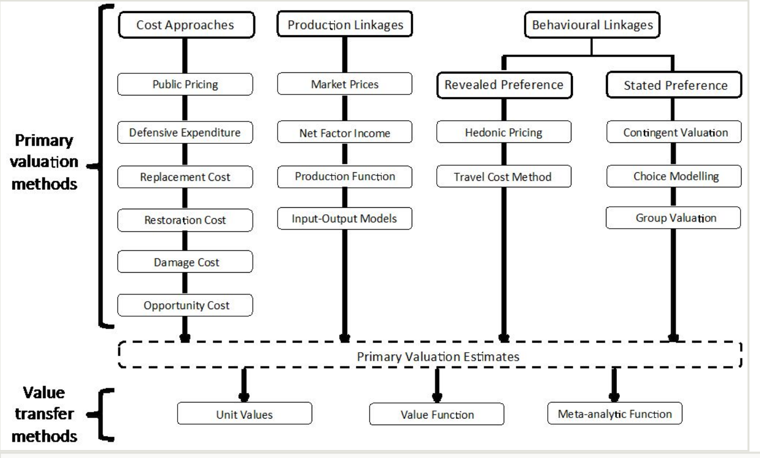

Figure 3.

Overview of primary valuation and value transfer methods (Brander et al. 2018: ESMERALDA D3.2)

Table 1.
Modelling methods - data and software needs and examples of detailed methods

Class	Data and software needs	Examples of methods
Phenomenological models describe relationships amongst biodiversity, ecosystems and ES by highlighting the biological mechanisms underpinning ES supply	Data: Information from other studies/ meta-analysis Land use or land cover (GIS data), soil conditions, climatic conditions, accessibility Software: Statistical software, GIS software, Independent modelling tool	Snow slide susceptibility model Schröter et al. 2014 http://dx.doi.org/10.1016/j.ecolind.2013.09.018 Preliminary assessment method (PAM) Zepp, H. et al. 2016 Link to publication
Macro-ecological models assess ES supply, based on the specific biodiversity components, such as species and habitat distribution, presence (or abundance).	Data: Species distribution data (e.g. Atlases, in-situ data) inventories Habitat / land cover data (GIS data), additional parameters: soil, climate, land use etc. Remote sensing to derive environmental variables and processes to be coupled with models. Software: Statistical software, GIS software, Independent modelling tool	Maximum entropy modelling (MAXENT) Vallecillo et al. 2016 https://doi.org/10.1016/j.ecolind.2016.05.008 Extensive Niche Modelling Rolf et al. 2012 http://dx.doi.org/10.1080/21513732.2012.686121
Trait-based models analyses ecosystem functions and, thus, ES by describing the relationship and interactions between species and environment.	Data: Observational or empirical data on functional traits, plant traits, traits of soil microorganisms. Explanatory variables: land use/ land cover, soil variables, climate variables. Software: Statistical software, GIS software, Independent modelling tool.	Utilisation of plant functional diversity Balzan et al. 2015 http://dx.doi.org/10.1111/eea.12403
Process-based models rely on the explicit representation of ecological and physical processes, such as carbon sequestration or nutrient cycling, that determine the functioning of ecosystems.	Data: High-quality data on climate, atmospheric CO2 concentrations, land use conservation, sequestration Software: Note: Process-based models require very good expertise to use the models properly.	KINEROS Nedkov & Burkhard 2012 http://dx.doi.org/10.1016/j.ecolind.2011.06.022 MedREM model Guerra, A. C. et al. 2014 http://dx.doi.org/10.1007/s10021-014-9766-4 MOSES Aitkenhead et al. 2011 http://dx.doi.org/10.1016/j.ecolmodel.2011.09.014

Statistical models are mathematical measures of the attributes of certain populations that are usually based on the estimation of the relationship between the response variable (i.e. ES) and explanatory variables (e.g. biophysical functions)	Data: Environmental variables Software: Statistical software (e.g. R, SPSS, MatLab) Visualisation could be done separately in GIS software.	K-mean cluster analysis Queiroz et al. 2015 https://doi.org/10.1007/s13280-014-0601-0 Principal Component Analysis (PCA) García-Nieto et al. 2015 https://doi.org/10.1016/j.ecoser.2014.11.00 Moran's Index Palomo, I. et al. 2014 https://doi.org/10.1007/s10113-013-0488-5
Ecological connectivity models evaluates the degree of the landscape to facilitate or impede the movement of different ecological processes.	Structural connectivity Data: Land cover or land use data, habitat data, features restricting movements, e.g. road and rail networks Functional connectivity Data: Species/ habitats distribution data, species suitability data, land cover or land use data, habitat data, features restricting movements, e.g. road and rail networks Software: Conefor (also plugin for Qgis or ArcGis available), Guidos, Fragstats, MatrixGreen, FunCon, GraphHab. Many calculations could be done separately in GIS software.	Conefor Vogt et al. 2007 https://doi.org/10.1016/j.ecolind.2006.11.001 Morphological spatial pattern analysis Esterguil et al. 2012 MSPA: European forest connectivity Conefor Vogt et al. 2009 https://doi.org/10.1016/j.ecolind.2008.01.011 Zonation Moilanen et al. 2005 https://doi.org/10.1098/rspb.2005.3164
State and transition models evaluates the specific conditions of systems by focusing on threshold points that can separate one system state from another by showing the transition between them.	Data: Temporal land use data, remote sensing data, Software: GIS-software, RS software	Land use scenario modelling Larondelle, N. & Haase, D. 2012 https://doi.org/10.1016/j.ecolind.2012.01.008 Carbon emission models Vleeshouwers & Verhagen 2002 https://doi.org/10.1046/j.1365-2486.2002.00485.x
Conceptual models are descriptions of a process which help to understand the subject behind the model.	Data: Information from other studies Software: Visualisation tools	Cascade model Haines-Young, R. and Potschin, M. 2010 Link to publication DPSIR Santos-Martin et al. 2013 https://doi.org/10.1371/journal.pone.0073249

Integrated modelling frameworks are tools designed specifically for ES modelling and mapping. They can integrate various biophysical, social and economic methods to model various services the ecosystems provide.	Data: Land cover data (GIS layers): terrain, vegetation, soil, bathymetry, habitat distribution etc., environmental statistics Software: GIS-software, stand-alone tools e.g. InVEST.	InVEST Lupa, P. 2016 Link to publication MCDA Comino, E. et al. 2014 http://dx.doi.org/10.1016/j.landusepol.2013.09.006