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Selecting methods for ecosystem service assessment: A decision tree approach

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Abstract

A range of methods are available for assessing ecosystem services. Methods differ in their aims; from mapping and modelling the supply and demand of ecosystem services to appraising their economic and non-economic importance through valuation techniques. Comprehensive guidance for the selection of appropriate ecosystem service assessment methods that addresse the requirements of different decision-making contexts is lacking. This paper tackles this gap using the experience from 27 case studies which applied different biophysical, socio-cultural and monetary valuation methods to operationalise the ecosystem service concept towards sustainable land, water and urban management. A survey of the reasons why the case study teams selected particular methods revealed that stakeholder-oriented reasons, such as stakeholder participation, inclusion of local knowledge and ease of communication, and decision-oriented reasons, such as the purpose of the case study and the ecosystem services at stake, were key considerations in selecting a method. Pragmatic reasons such as available data, resources and expertise were also important factors. This information was used to develop a set of linked decision trees, which aim to provide guidance to researchers and practitioners in choosing ecosystem service assessment methods that are suitable for their context.

Highlights

- Guidance is needed for selecting ecosystem service assessment methods
- Stakeholder participation was the key reason for selecting many methods
- The decision context and ecosystem services at stake were also important reasons
- Decision trees can help structure and rationalise the selection of ecosystem service assessment methods
- Linking decision trees with other forms of guidance addresses a broader range of user needs

Keywords

Guidance; Method; Tool; Decision trees; Biophysical; Monetary; Socio-cultural

1. Introduction

Research related to ecosystem service assessment has grown considerably over the last two decades (Luck et al., 2009; Martín-López et al., 2014; Vihervaara et al., 2010). Numerous efforts are also emerging where the concept is being applied to real-world situations with the goal of supporting sustainable land, water and urban management (Dick et al., this issue; Ruckelshaus et al., 2015; Saarikoski et al., this issue). The number of methods and tools that have been developed for assessing ecosystem services in specific situations is multiplying (Bagstad et al., 2013). These can be categorised as (i) *biophysical methods* for mapping ecosystem services, such as matrix or spreadsheet approaches (e.g. Burkhard et al., 2012; Kopperoinen et al., 2014), or modelling ecosystem services, such as InVEST (Sharp et al., 2016), E-Tree (Baró et al., 2015) or ESTIMAP (Zulian et al., this issue); (ii) *socio-cultural methods* for understanding preferences or social values for ecosystem services, such as deliberative valuation methods (e.g. Kelemen et al., 2013; Pereira et al., 2005), preference ranking methods (e.g. Calvet-Mir et al., 2012), multi-criteria analysis methods (e.g. Langemeyer et al., 2016; Saarikoski et al., 2016), and photo-elicitation surveys (e.g. García-Llorente et al., 2012a); and (iii) *monetary techniques* for estimating economic values for services, such as stated preference methods (Bateman et al., 2002) using contingent valuation (e.g. Gürlük 2006) and choice experiments (e.g. García-Llorente et al. 2012b), and revealed preference methods through the use of the travel cost method (e.g. Langemeyer et al., 2015; Martín-López et al., 2009) or hedonic pricing methods (e.g. Gibbons et al., 2014). The selection of a particular method to apply in a specific case can depend on many factors, including the decision-making context, the ecosystem services at stake, the strengths and limitations of different methods, and pragmatic reasons such as available data, resources and expertise.

Given this plethora of methods, guidance is essential to help researchers or practitioners who are new to ecosystem service assessment to be able to select and test relevant approaches that take account of their needs and constraints. This demand for guidance has been recognised (Bagstad et al., 2013, Martínez-Harms et al., 2014) and there is a growing pool of guidance documents for practitioners on how to include ecosystem services in policy and management decisions aimed at different sectors or stakeholder groups. Much of this guidance is published through websites and the grey literature, for example, the Royal Society for the Protection of Bird's (RSPB) Guidance Manual for Assessing Ecosystem Services at Natura 2000 sites (McCarthy and Morling, 2014); the Global Reporting Initiative's (GRI) Approach for Reporting on Ecosystem Services (GRI, 2011); the Ecosystem Services Guidance for the Oil and Gas Industry (IPIECA/OGP, 2011); the Convention on Biological Diversity's (CBD) Best Policy Guidance for the Integration of Biodiversity and Ecosystem Services in Standards (CBD, 2013); the Food and Agricultural Organisation's (FAO) Policy Support Guidelines for the Promotion of Sustainable Production Intensification and Ecosystem Services (FAO, 2013); the Business and Biodiversity Offsets Programme (BBOP) Biodiversity Offset Cost-Benefit Handbook (BBOP, 2009); and the UK Department for Transport's (DfT) guidance document on Applying an Ecosystem Services Framework to Transport Appraisal (Highway Agency/DfT, 2013). There are also a few academic papers related to general guidance for ecosystem service assessment (e.g. Gómez-Baggethun et al., 2016; Jacobs et al., 2016; Pascual et al., 2016; Seppelt et al., 2012). In addition, some guidance documents have been developed through major international initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) (see TEEB, 2011; 2013) and the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) guidance on the diverse conceptualisation of multiple values of nature and its benefits (IPBES, 2016a). The majority of these guidance documents describe an overall ecosystem service assessment approach broken down into steps and/or checklists sometimes with associated indicators and/or methods.

Several websites provide access to multiple ecosystem service methods or tools, for example, the Ecosystem Knowledge Network's Tool Assessor[1], the NEAT Tree Short Tool Reviews[2] and the ValuES Project Methods Database[3]. Most of these provide a limited selection of tools or methods which can be searched or filtered. Perhaps the most comprehensive is the ValuES inventory of methods which contains information on 65 techniques that can be filtered by purpose, method type and ecosystem service. Most of these approaches to providing method guidance have not been published in the academic literature and those which have been tend to focus on either broad literature reviews of methods or tools (e.g. Grêt-Regamey et al., 2016) or comparisons between specific sub-sets of methods. For example, Kelly et al. (2013) provide guidance for selecting amongst modelling approaches for integrated environmental assessment, Bagstad et al. (2013) compare 17 decision-support tools for ecosystem services quantification and valuation, and Gasparatos and Scolobig (2012) discuss how to choose the most appropriate sustainability assessment tool. Kenter et al. (2015) analyse a range of socio-cultural valuation methods in terms of their capacity to address different types of values, resource requirements and suitability for different spatial and time scales, while Vatn (2009) applies a theoretical approach to guide the selection of deliberative valuation studies. Bateman et al. (2002) and Ward and Beal (2000) are examples of manuals for selecting stated preference and travel cost methods, respectively. Pullin et al. (2016) analyse the strengths and weaknesses of knowledge synthesis methods that can be used to inform biodiversity and ecosystem services policy or management. Finally, Jacobs et al. (this issue) evaluate multiple biophysical, socio-cultural and monetary valuation methods to determine their suitability to elicit different value types, whilst assessing the data and resource requirements for their application.

In this study we aim to provide a more comprehensive guidance for coordinated selection of different biophysical, socio-cultural and monetary techniques for ecosystem service assessments based on their application in 27 case studies covering different land, water and urban decision-making contexts. Training and guidance was provided to the case study teams to implement a range of methods. We then surveyed the case study teams to understand the reasons why they selected particular methods and related these reasons to the characteristics, advantages and limitations of each method. This information was then used to develop a structured approach for ecosystem service method selection based on a set of inter-linked decision trees.

The paper is organised in four main sections. We first provide background information on the methods and case studies. We then present results showing which factors were key considerations for method selection across case studies and which features of the methods help to characterise their strengths and limitations, including how they differ from each other. We then describe how the decision trees were designed and tested in an iterative fashion between method experts and case study teams building on these results. Finally, we discuss the pros and cons of using decision trees for aiding the selection of specific biophysical, socio-cultural and monetary methods, compare this approach with other possible formats for providing similar guidance and illustrate how different forms of guidance might work together to better cover different user demands.

2. Method

The ecosystem service assessment methods were implemented and tested in 27 case studies as part of the EU-funded OpenNESS project (Jax et al., this issue). The case studies cover varying geographical regions and extents (Figure S1 in Supplementary Materials). Most (23) case studies are located in Europe with the remainder in Argentina, Brazil, India and Kenya. They focus on operationalising the ecosystem service concept in different management contexts, including sustainable urban

[1] http://ecosystemsknowledge.net/tool-search
[2] http://neat.ecosystemsknowledge.net/short-tool-reviews.html
[3] http://aboutvalues.net/about_values/

management, management of forest/woodlands, management of mixed rural landscapes, integrated river basin management, coastal area management, and commodity export management (Table S1 in Supplementary Materials). Further information on the specific issues addressed in each of the case studies is available in the OpenNESS case study book (Wijnja et al., 2016) and Dick et al. (this issue).

A wide variety of biophysical, socio-cultural and monetary methods covering 43 specific methods, categorised into 26 broad method groups, were proposed to the case studies as possible options for application (Table 1). Note that most case studies consisted of a number of sub-projects with different objectives to be delivered by the ecosystem service concept. Hence, most case studies applied more than one method. The specific methods that were offered to the case studies were limited by the expertise within the OpenNESS project, so we do not profess to be completely comprehensive in our coverage of all ecosystem service assessment methods and tools available. However, we aimed to cover most of the broad method groups used in ecosystem service assessment. The broad method groups shown in Table 1 were developed by the method experts in the OpenNESS project as a pragmatic way of presenting the methods to the case study teams.

Classifying methods into broad groups can be difficult as some methods are integrative by nature and span the groupings. Figure 1 provides a schematic illustration of these method groupings highlighting some of the key inter-linkages between them. Some methods can be relatively easily classified as a biophysical technique, such as ecological or hydrological models, as a socio-cultural technique, such as narrative analysis, or as a monetary technique, such as cost-based methods. However, for other methods this classification is not straightforward as they use or can elicit different types of ecosystem services values or may be classified differently depending on the specific aim of the application. For example, advanced matrix approaches such as GreenFrame (Kopperoinen et al. 2014; see Table 1) involve multiple datasets representing different types of values which are related to ecosystem service provision potential through a stakeholder process. Furthermore, some methods aim to integrate different types of data and values for a more comprehensive assessment, such as multi-criteria decision analysis and Bayesian belief networks. Finally, we also recognise that methods are not completely independent of each other. For example, there can be advantages from combining methods which build upon each other or from applying similar methods within a single case study to better capture uncertainties associated with particular methods. These issues are discussed in detail in Dunford et al. (this issue), whilst this paper focuses on the selection of individual methods while acknowledging this simplifying assumption. Table 1 provides examples of specific methods within each of the broad method groups focusing on those that were proposed to case studies.

Table 1: Overview of the ecosystem service assessment methods proposed to the OpenNESS case studies. Broad method groups are shown in the first column; examples of methods within the broad groups are shown in the second column. Methods in italics indicate those not chosen for application by case studies.

Method	Overview
METHODS THAT ARE BROADLY BIOPHYSICAL:	
Biophysical modelling	Biophysical models assess the biophysical factors (processes and functions) controlling ecosystem service supply. Many types of biophysical models can be relevant for ecosystem service assessment including: (i) ecological models, such as species distribution models (SDMs; e.g. Harrison et al., 2006); (ii) hydrological models, such as the Soil and Water Assessment Tool (SWAT; Francesconi et al., 2016); (iii) soil erosion models, such as the Revised Universal Soil Loss Equation (RUSLE; USDA, 2016); and (iv) state-and-transition models (STMs) which simulate ecosystem dynamics after disturbances based on alternate state theory and can be useful for understanding the importance of ecological functions that underpin the provision of ecosystem services (see Bestelmeyer et al., 2010).
Ecosystem service modelling	Ecosystem service models assess the supply (and sometimes the demand) of multiple ecosystem services usually in a specialised GIS-like software environment. They include models such as: (i) ESTIMAP, a set of spatially-explicit models each of which can be run separately for the assessment of different ecosystem services at the European or regional scale (Zulian et al., 2013a,b; Zulian et al., this issue); (ii) QUICKScan tool, a spatial modelling environment to combine expert knowledge with spatial and statistical data designed to be used in a facilitated workshop to enable policy-makers, experts and stakeholders to jointly explore the impacts of different policy options on ecosystem services (Verweij et al., 2016); (iii) InVEST, a set of models for mapping and valuing the ecological or economic value of multiple ecosystem services at a local to regional scale (Sharp et al., 2016); and (iv) the ES cascade model, a conceptual model highlighting the 'production chain' linking ecological and biophysical structures and processes with elements of human well-being (Potschin and Haines-Young, 2011).
Agent-based modelling	Agent-based models simulate the human decision-making process involved in ecosystem service management or policy. They can represent multiple organisational levels of human interactions with each other and their environment (e.g. Guillem et al., 2015).
Integrated Assessment modelling	Integrated assessment models (IAMs) couple together models representing different sectors or ecosystem components to simulate land use change and/or the delivery of ecosystem services. IAMs differ from ecosystem service models as they include feedbacks between the components that are coupled. Examples that were used in OpenNESS include: (i) SITE (SImulation of Terrestrial Environments), a software package to develop and apply models simulating regional land use dynamics (Schweitzer et al., 2011); (ii) *IMAGE-GLOBIO*, a global model which simulates past, present and future impacts of human activities on biodiversity and ecosystem services (Alkemade et al., 2009; Schulp et al., 2012); and (iii) *the CLIMSAVE Integrated Assessment Platform* (IAP; Harrison et al,. 2015), which combines ten sectoral models to analyse the impacts of different climate and socio-economic scenarios on ecosystem services, and possible adaptation options, at the European scale.
Simple GIS mapping	Basic method for mapping ecosystem services using GIS software if spatially-explicit data are directly available for a service (e.g. food production).

Method	Overview
Simple matrix mapping	Simple matrix mapping links a spreadsheet of ecosystem service supply/demand indicators by land cover category to a GIS map, to generate maps of ecosystem service supply, demand and balance (supply minus demand). The indicators can be derived from scientific data or can be scores based on local or expert knowledge (e.g. Burkhard et al., 2012).
Advanced matrix mapping	Advanced matrix mapping approaches build on simple matrix mapping approaches through incorporating multiple sources of spatial datasets. An example of such an approach used in OpenNESS is GreenFrame which was developed to assess spatial variation in ecosystem service provision potential of green infrastructure in spatial planning (Kopperoinen et al., 2014). The method utilises an extensive set of spatial datasets grouped into themes combined with both scientific experts' and local actors' scorings.
METHODS THAT ARE BROADLY SOCIO-CULTURAL:	
Deliberative mapping	Deliberative or participatory mapping is a broad group of methods which aim to include stakeholder's local knowledge, values and preferences in creating maps of ecosystem services. Several deliberative or participatory mapping methods were applied or developed within OpenNESS including: (i) Participatory GIS (PGIS) or Public Participation GIS (PPGIS) which uses workshops, face-to-face interviews or web-based surveys to integrate perceptions, knowledge (local-based or technical) and values of different stakeholders and presents the outputs in the form of a map of ecosystem services (see Brown and Fagerholm, 2015); (ii) MapNat App, a Smartphone app for mapping mainly cultural, but also some provisional and regulating, services and disservices; and (iii) BGApp, a Smartphone app for scoring different green and blue 'elements' of the landscape based on their importance for an ecosystem service, or a bundle of services, and an area-weighted score is calculated for a proposed property development.
Participatory scenario development	Scenarios are defined within the OpenNESS project as 'plausible, simplified description(s) of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces'. Engaging with stakeholders helps to formulate scenarios which are consistent with the stakeholder perspectives (Priess and Hauck, 2015).
Narrative analysis	Narrative methods aim to capture the importance of ecosystem services to people through their own stories and direct actions (both verbally and visually) (see de Oliviera and Berkes, 2014).
Deliberative valuation	Deliberative valuation is not one particular valuation method, but it is a valuation paradigm providing a framework to combine various tools and techniques that bridge citizens and academia, as well as different disciplines within science. Such methods invite stakeholders and citizens (the general public) to form their preferences for ecosystem services together through an open dialogue with others (see Wilson and Howarth, 2002).
Preference assessment	Preference assessment is a direct and quantitative consultative method for analysing perceptions, knowledge and associated values of ecosystem service demand or use (or even social motivations for maintaining the service) without using economic metrics. Data is collected through surveys using a consultative approach with different variations, such as free-listing exercises, ecosystem service ranking, rating or ecosystem service selection (e.g. Martín-López et al., 2012), sometimes also using visual stimuli (e.g. photos as illustrations of ecosystem services as in the case of the Ecosystem Services card game).
Photo-series analysis	Photo-sharing websites such as Flickr, Panoramio and Instagram are used to provide revealed preferences for cultural ecosystem services, assuming that visitors are attracted by the location where they take photographs (e.g. Richards and Friess, 2015).

Method	Overview
Photo-elicitation	This method aims to translate people's visual experiences and perceptions of landscapes in terms of ecosystem services. Respondents to questionnaires specify the principal ecosystem services provided by each landscape from a list of potential services provided by the area (e.g. López-Santiago et al., 2014).
Time use studies	This method is an innovation of the conventional stated preference techniques taken from the contingent valuation approach (see monetary methods below). Surveys are used to estimate the value of ecosystem services by asking people how much time they would be willing to invest for a change in the quantity or quality of a given service (García-Llorente et al., 2016).
METHODS THAT ARE BROADLY MONETARY:	
Cost-effectiveness analysis	Cost-effectiveness analysis is a decision-support tool for ranking alternative ways of meeting the same policy goal by their ratio of effectiveness to cost (see Boardman et al., 2006).
Benefit-cost analysis	Benefit-cost analysis is a decision-support tool for screening alternatives by their internal rate of return, or ranking alternatives by their discounted benefit/cost ratio or net present value (see Boardman et al., 2006).
Market price / exchange-based methods	Values are observed directly or derived from prices in markets. This is a large category of monetary methods which includes cost-based methods. Revealed preferences methods (below) are sometimes included in exchange-based methods, because market prices (house prices, costs of travel) are used to derive values of ecosystem services indirectly. *Shadow pricing* is also an implicit form of market price defined as the marginal price society 'puts' on the provision of non-marketed ecosystem services through setting environmental targets (e.g. Konrad et al., 2017). Mitigation cost-based valuation methods are a group of 'exchange-based' techniques that use the cost of actual measures to maintain ecosystem service provision as a proxy for the value of actions undertaken in the mitigation hierarchy (BBOP, 2009), including actions to avoid, minimise, restore or replace ecosystems and their services that are potentially at risk in connection with a development. As a valuation technique, the costs of actions are taken as proxies for the value of the ecosystem services lost. This group of methods therefore includes: (i) restoration cost; (ii) replacement cost; and (iii) clean-up cost.
Revealed preference methods	Values of ecosystem services are revealed indirectly through purchases (e.g. house prices) or behaviour (travel costs). Examples used in OpenNESS include: (i) hedonic pricing, which is the study of multi-correlation between environmental characteristics of a good and its sales price; and (ii) travel cost methods (TCM), which are based on the observation that recreational services can only be realised through physical access to nature.
Stated preference methods	Stated preference valuation is a family of economic valuation techniques which use individual respondents' stated hypothetical choices to estimate change in the utility associated with a proposed increase in quality or quantity of an ecosystem service or bundle of services (Bateman et al., 2002). The methods include: (i) contingent valuation; (ii) choice experiments; and (iii) contingent ranking among others.
Resource rent	The resource rent method derives the value of the ecosystem service as a residual after the contributions of other forms of capital have been deducted from the operating surplus (e.g. Obst et al., 2016)

Method	Overview
Simulated exchange	Based on a derived demand function it is possible to estimate a marginal exchange value by choosing a point along the demand function, either based on observed behaviour or through intersection with a modelled supply curve. This is an experimental method proposed for ecosystem accounting (see Campos and Caparros, 2011; Obst et al., 2016).
Production/cost function	These approaches relate the output of marketed goods to the inputs of ecosystem services through the use of econometric techniques (e.g. Bateman et al., 2010).
Value transfer	Benefits transfer (BT), or more generally - value transfer (VT) - refers to applying quantitative estimates of ecosystem service values from existing studies to another context (see Johnston et al., 2015).
INTEGRATIVE METHODS:	
Bayesian Belief Networks (BBN's)	BBNs are based on a graphical structure consisting of nodes representing, for instance, processes or factors, and links specifying how the nodes are related. BBNs can be constructed from a combination of historical data and expert knowledge, but BBNs representing ecosystem services are mainly derived from expert knowledge as historical data is sparse. Each link represents a dependence relation such that each node has a conditional probability distribution specifying the (causal) relationship between the values of nodes with incoming links to the node and the values of the node itself. This means that uncertainty is explicitly taken into account (see Smith et al., this issue). BBNs can be linked to GIS to undertake spatial analysis.
Multi-criteria Decision Analysis (MCDA)	MCDA is an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. Spatial MCDA are carried out in GIS in order to enable a visualization of the multiple criteria (see e.g. Munda, 2004).

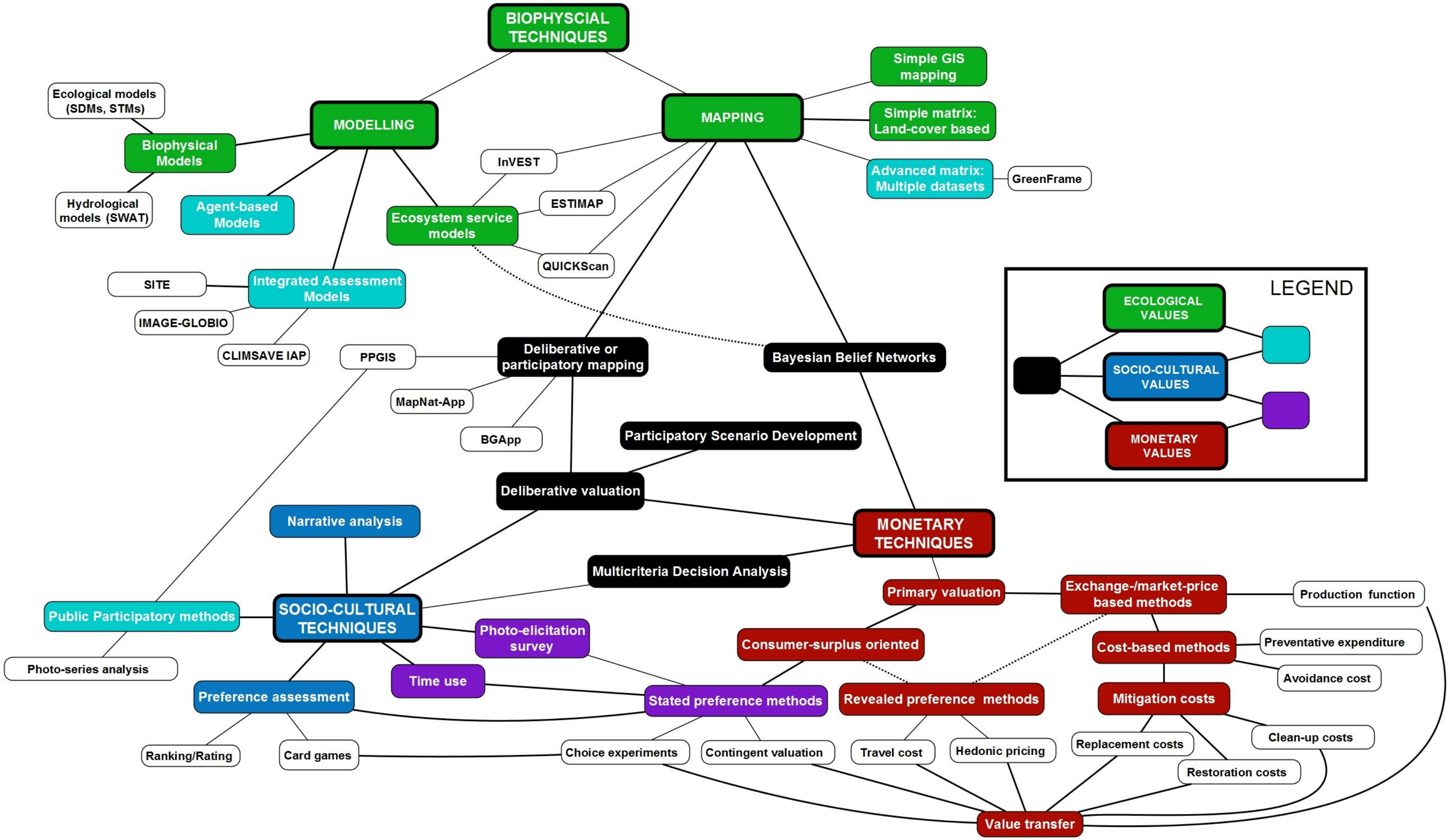


Figure 1: Schematic illustrating broad method groupings and the inter-linkages between them. Broad method groups are colour-coded by the types of values they encompass (individual or combinations of value types). Boxes with white background represent examples of specific methods (see Table 1).

Linking of the methods to the OpenNESS case studies and providing guidance and training to implement the methods was an iterative process following the timeline presented in Figure 2. Firstly, a questionnaire was circulated to the case studies to collate information on their decision-making and thematic focus (i.e. purpose of the case study, ecosystem services of interest, relevant stakeholders), the level of experience they had with different types of methods, the data they had available, and if they already had a method which they planned to use.

Secondly, a workshop was held in which case study researchers and method experts discussed the different types of methods and how they fitted with the case study objectives and workplans. This led to a first matching of methods to case studies. During this exercise not all methods proposed to case studies were chosen for application. However, the methods that case studies selected covered 21 of the 26 broad groups shown in Table 1. Those not selected are shown in italics in Table 1, and cover agent-based modelling and several of the monetary techniques reflecting the relatively lower proportion of economists in the project. In addition, the broadscale methods (IMAGE-GLOBIO and CLIMSAVE IAP within the Integrated Assessment Models broad group) were not specifically used by case studies due to mismatches in scale. Instead, they were used in the project to provide a broadscale context in which the case study applications took place.

Figure 2: Timeline of method selection process.

A set of detailed guidelines were then written for all methods explaining the types of problem the method can be used to study, its data requirements, its constraints and limitations, the steps required to apply the method within a case study, worked examples of the practical application of the method, and further reading for use by the case studies in implementing their selected method(s). These method factsheets have been uploaded to an online platform for sharing information on natural capital, ecosystem services and nature-based solutions known as Oppla (see http://oppla.eu/marketplace). This written guidance was supported by a dedicated 2-day training workshop and supplemented by various case study visits by method experts, and method clinics and specific training sessions at project meetings.

Once case studies had sufficiently progressed in the application of methods, a survey was implemented to gather information on the reasons why case studies had chosen particular methods. This first survey was in the form of an open question on why case studies had selected methods so as not to influence the outcome. This was followed by a group exercise at a project meeting where case studies compared and supplemented (where necessary) their reasons for method selection and drafted simple schematics illustrating their decision process for method selection.

In parallel to the method training, groups of method experts within the project worked together to classify the key features of each method that related to its application (e.g. requirements, strengths, limitations, scale, etc) drawing on the method factsheets. This was undertaken for all method groups in Table 1, not just those selected for application by the case studies, in order to determine how different methods could be differentiated from each other.

The information from the case studies and the method experts was consolidated and used to create draft decision trees for biophysical, socio-cultural and monetary methods. The draft decision trees were then tested with the case studies in a facilitated workshop where each case study compared their own experience with the decision nodes and pathways represented on the trees. This was first undertaken independently for each case study and then in a joint learning session which identified overall points for improving the decision trees.

A follow-up survey was also implemented to check if case studies wished to amend their reasons for selecting methods after completion of the method application. This second survey was structured according to a fixed set of questions where case studies were asked to provide a numeric score on "to what extent a particular reason was relevant to the selection of a specific method (0=definitely not; 1=to some extent; 2=definitely)". In addition, case studies could provide a comment to support their score. Finally, the group of method experts used the outputs from the workshop and the follow-up survey to revise and inter-link the three decision trees.

3. Results

3.1 Reasons for method selection

The surveys revealed a wide variety of factors that were considered when case studies selected a method. The reasons for selection could be broadly grouped into four categories: methodology-oriented; research-oriented; stakeholder-oriented; and decision-oriented. The latter category can be sub-divided into reasons related to the overall purpose of the case study and the ecosystem services at stake. Note that the results from the surveys only cover those methods applied in the case studies from Table 1, i.e. not the methods shown in italics which were only evaluated by the method experts (see Section 3.2).

Methodological reasons included whether data required by a method was available in the case study, whether expertise was available either in the case study team or in the OpenNESS project, the amount of time a method took to apply, and the financial resources required to apply a method.

Research-oriented reasons included whether the method was considered to be novel in terms of advancing knowledge or addressing a research gap, whether the method was considered to be a recognised or established approach, whether the method could be replicated across sites or case studies to compare results, whether the approach was holistic in terms of improving understanding of the full system being studied rather than specific components, and whether the approach could be used to explore or address uncertainty.

Stakeholder-oriented reasons could be broadly divided between facilitating stakeholder participation and the co-design/co-production of knowledge. The former was cited as an important reason for selecting methods that encouraged stakeholder dialogue and deliberation, or fostered social learning. The latter was cited for methods that were primarily chosen by the stakeholders involved in the case study advisory boards and for the inclusion of local knowledge as part of the method application. Having a method and/or results from the method that were easy to communicate to stakeholders was also cited as an important consideration for method selection that underpinned the other stakeholder-oriented reasons.

Decision-oriented reasons included whether the case study focus was on the current and/or future state of ecosystem services, and whether it was concerned with specific services or groups of services (i.e. cultural, regulating or provisioning) or with multiple ecosystem services and the trade-offs between them. This category also included several reasons related to the overall purpose of the case study, i.e. whether it was to raise awareness of the importance of ecosystem services, assess trade-offs between services, resolve potential conflicts, evaluate existing policies or projects, inform spatial planning, screen/rank alternatives, set targets for standards or incentives, or guide damage compensation. Further discussion of the decision-support purpose of the case studies is provided in Barton et al. (this issue). Issues of scale are also covered within this category as decision-support may require spatially-explicit assessment, or an assessment covering different spatial or temporal scales. Finally, whether the case study required monetary or non-monetary outputs was also cited as an important reason for method selection.

Figure 3 shows the percentage of times that the different reasons were cited by case studies across all methods. Stakeholder-oriented considerations are the most common (45%). Decision-oriented reasons are also frequently cited (33%), but these are highly variable across the category with some reasons such as the ability of a method to assess the current state (60%) and raise awareness of the importance of ecosystem services (59%) being highly cited whilst others, such as setting targets for standards, policies, pricing/incentive levels, or damage compensation being rarely cited (4 to 8%). Within the decision-oriented category the ecosystem service category of interest (i.e. provisioning, regulating, cultural or supporting services; shown in hatching in Figure 3) is a frequent reason for method choice (36%), particularly for quantifying cultural ecosystem services (51%). Selecting methods that can be applied to multiple services (41%) to assess trade-offs (31%) are also notable factors. Research- and method-oriented considerations are also important (32% and 27%, respectively), particularly the perceived novelty and potential for further development of a method (48%), and the expertise available for implementing a method (43%).

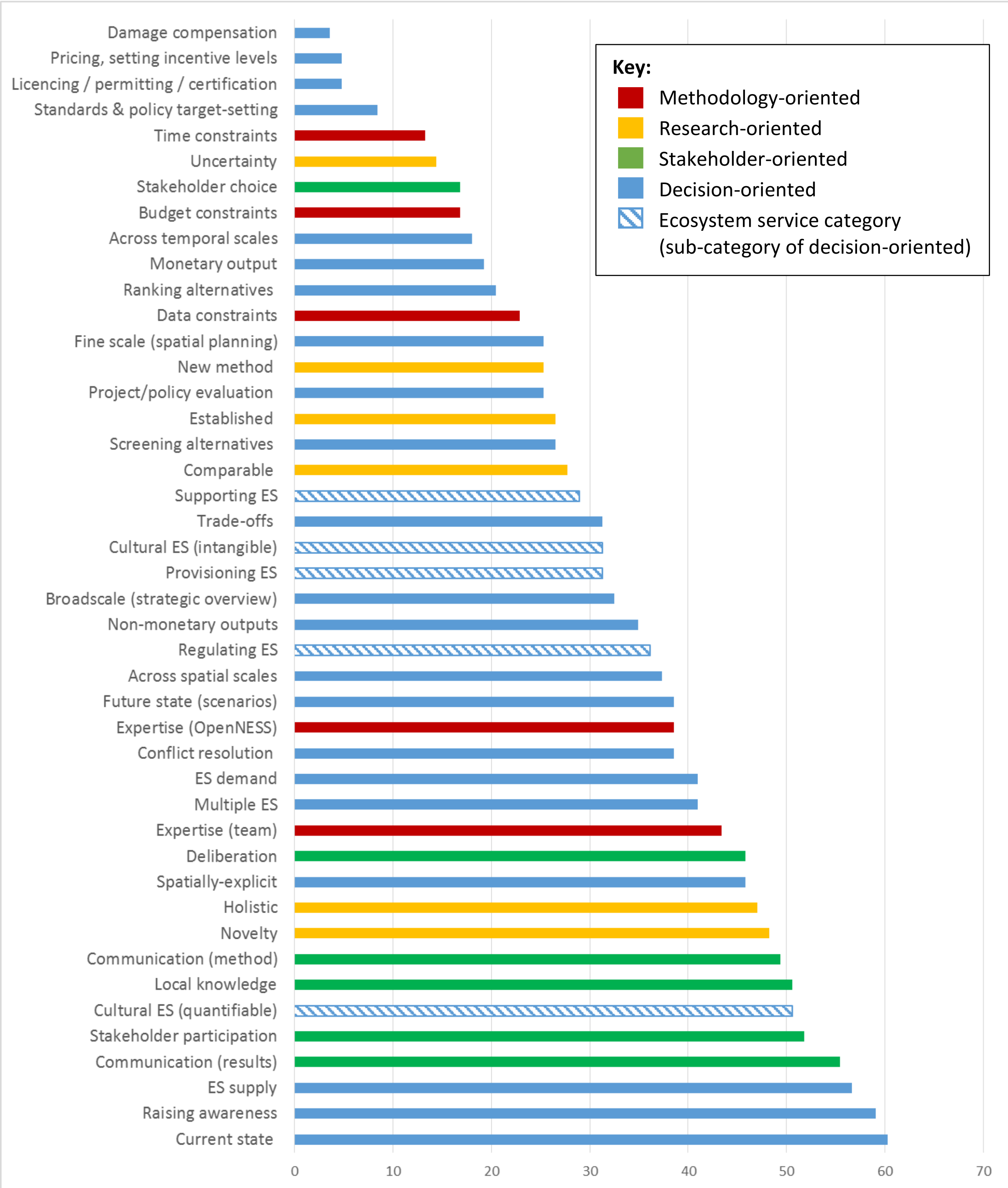


Figure 3: Percentage of times a reason was given as being a major consideration for ecosystem service (ES) method selection across all case studies (N=83). Colours show the different categories of the reasons (see key).

Looking at the considerations by method group highlights some interesting patterns (Figure 4; the same results by individual method are given in Figure S2 in Supplementary Materials). The biophysical methods tend to be associated with spatially-explicit assessments of ecosystem service supply across a range of ecosystem service categories, although the biophysical models focus solely on provisioning and regulating services. This enables the majority of these methods to cover multiple services and assess trade-offs. Most of the biophysical methods were chosen to assess the current state, but the assessment of future scenarios was also an important consideration for the three types of modelling approaches. Methods were selected for raising awareness of the importance of ecosystem services, particularly for the matrix approaches, where ease of communication to stakeholders was highlighted as important.

Out of the methodology-oriented considerations, available expertise within the case study team (biophysical models, integrated assessment models and simple matrix) or within the OpenNESS project (ecosystem service models and advanced matrix) were key reasons for their selection. The research-oriented reasons vary by method group, but novelty and holistic approaches were suggested most frequently. Stakeholder-oriented reasons for selection were rare for the majority of biophysical methods.

Socio-cultural methods, not surprisingly, have a high proportion of stakeholder-oriented considerations for their selection compared to other method types. In terms of decision-oriented reasons, they were generally selected to produce non-monetary outputs for multiple ecosystem services to raise awareness, assess trade-offs or resolve conflicts. Most methods were used to assess the current state, although the future state was considered in some methods (participatory scenarios, deliberative mapping, deliberative valuation and time use studies). The method of narrative analysis shows a much wider range of decision-oriented reasons than the other socio-cultural methods covering most of the decision-oriented classes. In terms of methodological-oriented reasons, expertise within the case study team was the most important reason for selection, whilst novelty and holistic approaches were given as the main research-oriented reasons (the latter being similar to the scores for biophysical methods).

The monetary methods, not surprisingly, score very highly on being selected because they produce monetary outputs. They are also associated with a wide range of stakeholder-oriented reasons, with the exception of benefit-cost analysis. Out of the stakeholder-oriented reasons, stakeholder participation and ease of communication of the method and its results were cited as being particularly important. Methodological-reasons related to existing expertise within the case study team and data, time and resource constraints were also stated as being important, particularly for value transfer approaches.

In constrast to biophysical and socio-cultural methods, the most important research-related reasons for selection of monetary methods were comparability and having an established method. In terms of decision-oriented reasons, monetary methods were predominantly applied to raise awareness, but also for assessing trade-offs, resolving conflicts, evaluating projects and screening alternatives. The majority of monetary methods focused more on ecosystem service demand than supply, particularly for cultural services such as recreation.

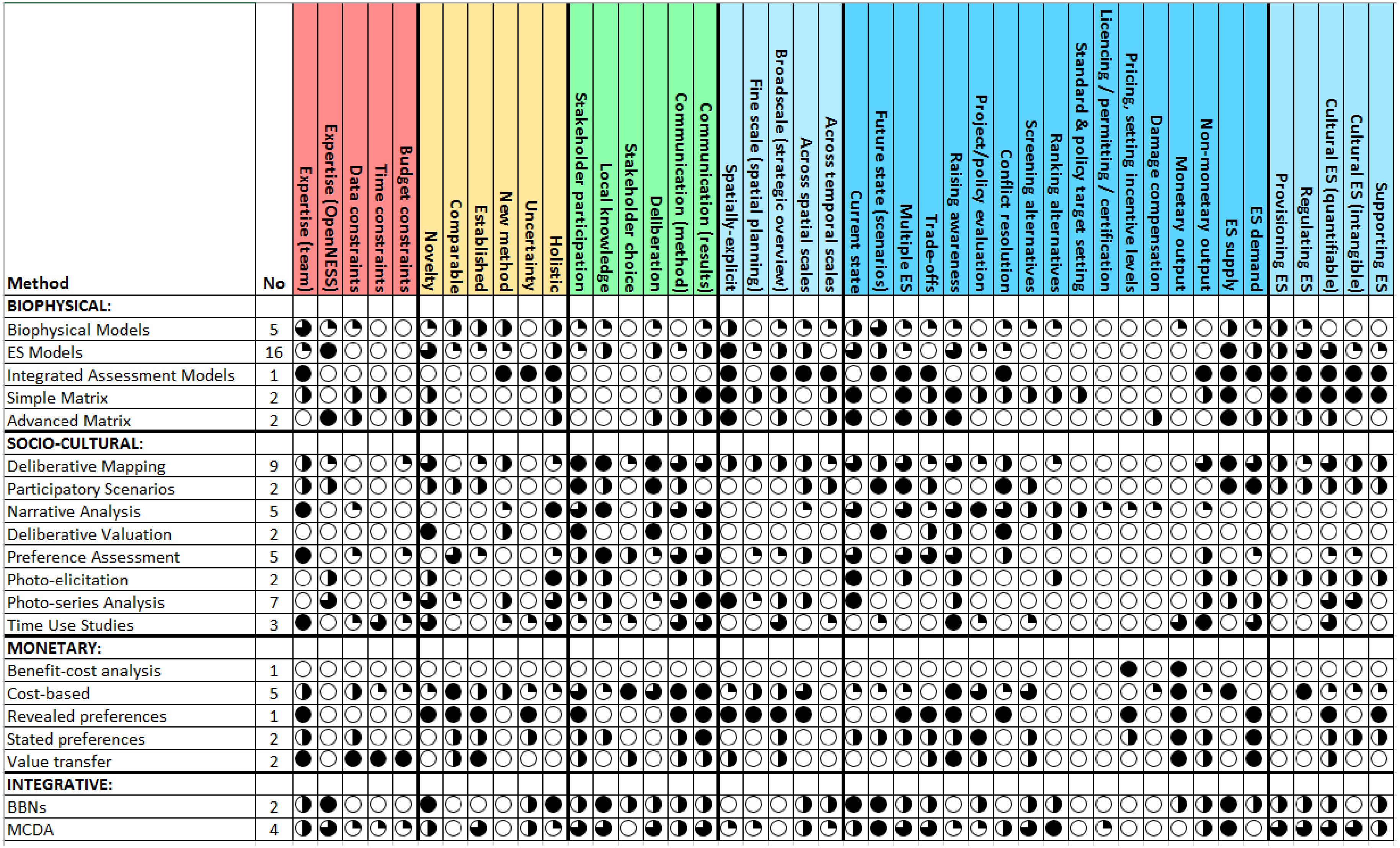


Figure 4: Reasons for ecosystem service (ES) assessment method selection summarised by broad method group. Pie charts indicate fraction of case studies indicating the reason as a major consideration for method selection: full black = 100%; full white = 0%; inbetween values shown in fractions of 25%. No = number of case studies applying the method and completing the survey. Colours show the reason categories are explained in Figure 3.

The two types of integrative methods, Bayesian belief networks (BBNs) and multi-criteria decision analysis (MCDA), were chosen for a broad range of reasons spanning all four categories. Expertise was the most relevant methodology-oriented reason and novelty, a holistic understanding and the ability to explore uncertainty were the most relevant research-oriented reasons influencing method selection. Both types of method had a high proportion of stakeholder-oriented considerations for their selection, but a relatively low proportion of scale-related (temporal and spatial) reasons. They were applied for a wide variety of decision contexts including assessment of the current and future state of multiple ecosystem services to explore trade-offs, or develop criteria for screening or ranking alternatives. See Barton et al. (this issue) for an analysis of patterns of method application to different decision contexts.

3.2 Key features of methods that may influence their selection

Each method has specific features which inform its relevance or appropriateness for application to a certain decision or problem context in a case study. Table 2 classifies the broad method groups according to key criteria or features that may be important for method selection. These features were defined by method experts in the project according to their expert judgement for all the method groups in Table 1 (i.e. not just those applied in the case studies). Method experts defined a set of features across biophysical (Table 2a), socio-cultural (Table 2b) and monetary (Table 2c) methods covering reasons for which a method may be applied, the ability of a method to integrate different criteria, scale-related features of a method, and pragmatic features related to data and expertise. For each of these features, the method experts identified whether it was key for method selection, often not the main reason for method selection but still of some importance, or only rarely of importance for method selection. This was first undertaken for the three types of methods (biophysical, socio-cultural and monetary) independently and then iterated between the different groups of method experts to ensure that the scoring was consistent.

This information forms a different source of knowledge to the empirical evidence for method selection given by case studies in the previous section. However, the two sources of information are likely to be related. For example, often it can be pragmatic reasons that dominate the selection of a method - expertise, data and resources are crucial underpinning needs for some methods. Such reasons emerge because some methods are highly data intensive and/or require advanced expertise in specific disciplines or detailed knowledge of specific software. Many modelling (Table 2a) and monetary valuation (Table 2c) approaches fall into this category, such as biophysical models, ecosystem service models, and primary valuation studies using stated preference methods and benefit-cost analysis. Such approaches also tend to require large amounts of quantitative data and a significant investment of time for their implementation. Alternatively, other methods are relatively more straightforward to apply without specific expertise or needs for substantial data or resources, such as matrix-based mapping approaches (Table 2a), deliberative mapping approaches (Table 2b), value transfer approaches (Table 2c) or photo-series analysis (Table 2b). Integrative methods, such as BBNs (Table 2a) and MCDA (Table 2b), tend to fall between these two extremes being able to take advantage of both qualitative and quantitative data that is available in a case study, but still requiring significant skills and resources to implement.

The ability of a method to address a specific purpose may be the primary factor influencing method selection. Most methods are able to characterise the current state of ecosystem service demand or supply, whilst only a few have the ability to explore potential future service provision, such as the biophysical modelling approaches (Table 2a) and participatory scenario development (Table 2b), the latter being specifically designed to address this purpose. Some methods focus on specific ecosystem services, such as biophysical models of soil erosion (Table 2a), or specific groups of services, such as photo-series analysis of cultural ecosystem services (Table 2b). Alternatively, other methods attempt to provide a more holistic or strategic overview of multiple ecosystem services which may be used to assess trade-offs between the supply of different services (e.g. matrix-based approaches; Table 2a) or the demand for services by different stakeholders (e.g. PGIS, preference assessment methods, photo-elicitation or MCDA; Table 2b). The purpose for a monetary valuation study is particularly important in method selection as shown in Table 2c. For example, exchange-based, cost-based or value transfer methods may be used to inform asset accounting, whilst stated preference techniques may support incentive design or pricing.

A study may aim to improve understanding between stakeholder groups, making them aware of how different people and groups perceive the trade-offs between ecosystem services so helping to resolve conflicts (Rodela et al., 2017). Methods which promote stakeholder participation or incorporate local knowledge can be useful in such circumstances, such as deliberative or participatory mapping, narrative analysis, deliberative valuation, MCDA (Table 2b) and advanced matrix approaches (Table 2a). Deliberative methods can facilitate social learning by creating a space for dialogue and reflection between different stakeholder groups, leading to the co-creation of knowledge. Some approaches can be implemented with or without stakeholder input, such as simple matrix-based approaches where the scoring of datasets for their ability to supply ecosystem services can be undertaken by an expert or stakeholder group depending on the study design. How easy a method is to understand or communicate is also highly relevant to method selection, particularly for studies which aim to foster social learning, inform decision-making or simply raise awareness of the importance of ecosystem services. This is particularly the case for many of the socio-cultural methods (Table 2b) and the simpler ecosystem service mapping approaches (Table 2a).

The purpose of a study frequently affects the choice of spatial and temporal scale and the need for spatially- or temporally-explicit outputs. Obviously all of the mapping approaches are spatially-explicit and many of the modelling approaches can be spatially- or temporally-explicit depending on the process(es) or phenomena they are simulating (Table 2a). Photo-series analysis is also spatially-explicit as the spatial coordinates of each photo are used as part of the assessment (Table 2b). Revealed preference methods for monetary valuation may also rely on spatially-explicit data, e.g. using the proximity between specific ecosystem characteristics and properties to reveal the dependence of property values on ecosystem services (Table 2c). Some monetary techniques are temporally-explicit such as benefit-cost analysis giving specific attention to distribution of costs and benefits over a predefined time period for the alternatives under consideration (Table 2c). Revealed preference valuation methods are based on statistics of consumer behaviour for a defined time period, and stated preference methods should define the period they wish respondents to consider in order to be more reliable. As a rule of thumb, valuation methods that are not temporally and spatially-explicit are not choice specific, and by extension are not relevant for decision-support.

Table 2: Criteria for selecting different methods. Key: X = key feature or very important criteria for method selection; * = possible feature/some importance for method selection; ~ rare feature; + = only a relevant criteria if integrated or combined with other ecosystem service mapping or modelling techniques.

a) Biophysical methods

Criteria	Biophysical models	Ecosystem service models	Agent-based models	Integrated assessment models	Deliberative / participatory mapping	Simple matrix	Advanced matrix	Bayesian Belief Networks
Characterisation of current state	X	X	X	X	X	X	X	X
Exploration of futures	X	X	X	X				*
Holistic understanding of social-ecological system dynamics		*	X	X	*		*	X
Addresses multiple ecosystem services		X	+	+	X	X	X	X
Enables trade-offs to be explored		X	+	+	X	X	X	X
Facilitates social learning	*	*	X	*	X	X	X	*
Informs decision-making	*	*	*	*	X	*	X	*
Stakeholder participation	*	*	*	*	X	*	X	*
Incorporates local knowledge	~	*	X		X	*	X	*
Easy to communicate					X	X	X	~
Transparent (easy to understand)					X	X	X	*
Integrated treatment of issues		X	X	X	X	*	*	X
Integration across disciplines		X	X	X	X	X	X	X
Integration of socio-ecological processes		*	X	X	~		~	*
Integration of spatial scales (cross-scale)	*	*	*	*				
Integration of temporal scales (cross-scale)	*	*	*	*				
Spatially-explicit	*	X	*	*	X	X	X	*
Temporally-explicit	*	*	X	X	*	*	*	*
Requires time series data	*		*	*				*
Mainly quantitative data	X	X	X	X	*	X	X	*
Mainly qualitative data		*	*		X	*	*	X
Data intensive	X	X	X	X			*	X
Addresses uncertainty	*	*	*	*				X
High level of expertise needed	X	X	X	X			*	X
Large amount of resources needed	X	X	X	X	*		*	X

b) Socio-cultural methods

Criteria	Preference assessment	Photo-elicitation	Photo-series analysis	Narrative analysis	Participatory scenario development	Deliberative valuation	Time use	Multi-criteria decision analysis (MCDA)
Characterisation of current state	*	*	*	*		X	*	X
Exploration of futures				*	X	*		*
Holistic understanding of social-ecological system dynamics	*	*	*	*	*	X	*	*
Addresses multiple ecosystem services	X	X	*	X	X	*	X	X
Enables trade-offs to be explored	X	X	*	X	X	*	X	X
Facilitates social learning	*	*		X	X	X	*	X
Informs decision-making	*	*	*	*	X	*	*	X
Stakeholder participation	X	X		X	X	X	X	X
Incorporates local knowledge	X	X		X	X	X	X	X
Easy to communicate	X	X	X	X	X	X	X	X
Transparent (easy to understand)	X	X	X	X	X	X	*	X
Integrated treatment of issues	*	X			X	X	*	X
Integration across disciplines	*	*			*	*	*	X
Integration of socio-ecological processes					*	*		X
Integration of spatial scales (cross-scale)	*	*			*	*	*	*
Integration of temporal scales (cross-scale)	*	*			X	*	*	*
Spatially-explicit	*		X	*		*	*	*
Temporally-explicit					X			*
Requires time series data								*
Mainly quantitative data	*	*	X				X	*
Mainly qualitative data	*	*	X	X	X	X		*
Data intensive	*	*		X			X	X
Addresses uncertainty					X		*	
High level of expertise needed				*			X	X
Large amount of resources needed	*	*	*	*	X	*	X	X

c) Monetary methods (CEA = cost-effectiveness analysis; BCA = benefit-cost analysis).

Criteria	Source of data		Types of individual valuation methods			Decision-support tools	
	Primary study	Value transfer	Stated Preference	Revealed preference	Exchange-based & cost-based	CEA	BCA
Reason for valuation[4]:							
Explorative – method development	X	*	X	X	X	X	
Informative - Awareness raising	*	X	*	*	X	*	*
Informative - Asset accounting	*	X		*	X		
Decisive - Priority-setting	*	X	X	*	*	X	X
Technical - Incentive design, pricing	*		X	~	*		*
Technical - Litigation/Fines	~		~	~	*		*
Addresses multiple ecosystem services	*	*	*	*			X
Enables trade-offs to be explored	*	*	X	X		X	X
Stakeholder participation			*	~		*	*
Incorporates local knowledge			X			*	*
Easy to communicate	X	*	X	*	X	X	*
Transparent (process easy to understand)	X	*	*	*	*	*	*
Integrated treatment of issues			X	*	*	*	X
Integration across disciplines			X	*		*	X
Integration of processes (with governance)			*	~	X	*	~
Integration of spatial scales (cross-scale)			~			~	*
Integration of temporal scales (cross-scale)			~			X	X
Spatially-explicit			*	X	~	*	*
Temporally-explicit			X	X	X	*	X
Requires time series data				X	*	*	X
Mainly quantitative data	X	X	X	X	X	X	X
Mainly qualitative data							
Data intensive	X		X	X	*	*	X
Addresses uncertainty:	X	*	X	X	*	*	*
High level of expertise needed	X	*	X	X		*	X
Large amount of resources needed	X		X	X		~	X

[4] See Barton et al. (this issue) for further details on reasons for valuation.

For some users there are specific aspects of the system where they feel they need evidence and advice in making decisions, but for many there is a need for a comprehensive perspective balancing all evidence. Taking an integrative approach whereby a study takes account of multiple issues, values, socio-ecological processes and/or disciplines (including multiple stakeholder views) may be a valuable feature of a method. Integration is addressed to different degrees by different methods often depending on their primary focus. For example, integrated assessment models aim to simulate multiple socio-ecological processes through coupling different sectoral models (Table 2a). Alternatively, multi-criteria decision analysis aims to evaluate the performance of alternative courses of action (e.g. management or policy options) with respect to criteria that capture the key dimensions of the decision-making problem (e.g. ecological, economic and social sustainability), involving scenario assessments, human judgment and preferences (Table 2b). Bayesian belief networks can be used to integrate mapping and model simulation results with qualitative and quantitative assessment of preferences to conduct scenario and decision analysis that accounts for uncertainty across the different methods (Table 2a).

Whether a method explicitly addresses or enables the exploration of uncertainty may be a critical consideration when choosing a method. Some methods, such as BBNs (Table 2a), are designed to deliberately explore issues of uncertainty using conditional probability tables, whilst other methods such as the modelling approaches (Table 2a) or time use studies (Table 2b) can explore uncertainty if this is factored into the methodological design. For the monetary techniques, key considerations related to uncertainty are the accuracy and reliability of the ecosystem service value estimates derived (Table 2c). Primary valuation studies tend to be designed with specific attention to these aspects, as the suitability of the value estimates for cost-benefit assessment of public investment often requires evaluation of uncertainty.

3.3 The decision trees

The surveys of reasons for method selection by the case study teams (Section 3.1), the assessment of the key features of the different method groups by the method experts (Section 3.2) and existing guidance documents were used to develop decision trees to structure and guide the process of method selection. We decided to develop three decision trees divided into biophysical, socio-cultural and monetary methods for practical reasons; developing a single decision tree encompassing all methods was considered to be confusing due to its complexity. Rather the three decision trees include some common integrative methods and are inter-linked to highlight that there may be a need to move between them when being guided through the process of method selection.

A draft set of decision trees was developed and tested by the case study teams in a workshop (October 2015, Figure 2). In a series of sessions each case study worked with an individual facilitator to describe: (i) the decision process that they followed in practice when they decided which methods to use; (ii) the extent to which the decision trees matched the case studies' 'true' experience of deciding between methods; and (iii) how they would improve the decision trees so that they might be more useful for others. Most case studies found the decision trees broadly useful, but stated that they present a simplified coarse level view compared to the real and detailed context of the case studies. Several suggestions were made for potential improvements which would make the decision trees more widely applicable and useful for a non-specialist, including starting each decision tree with a similar question related to the purpose of the ecosystem service study, moving away from a bimodal to a multi-modal structure with less strict (i.e. yes/no) choices, making the questions on the decision tree nodes more concrete, and simplifying the language. These broad suggestions and many specific recommendations were used to create the final versions of the decision trees shown in Figure 5.

To further increase the robustness of the decision trees, we took account of existing guidance documents such as those listed in the Introduction and relevant literature. Furthermore, we had several rounds of iterations with experts of individual methods to find out how to best differentiate between the branches of the trees.

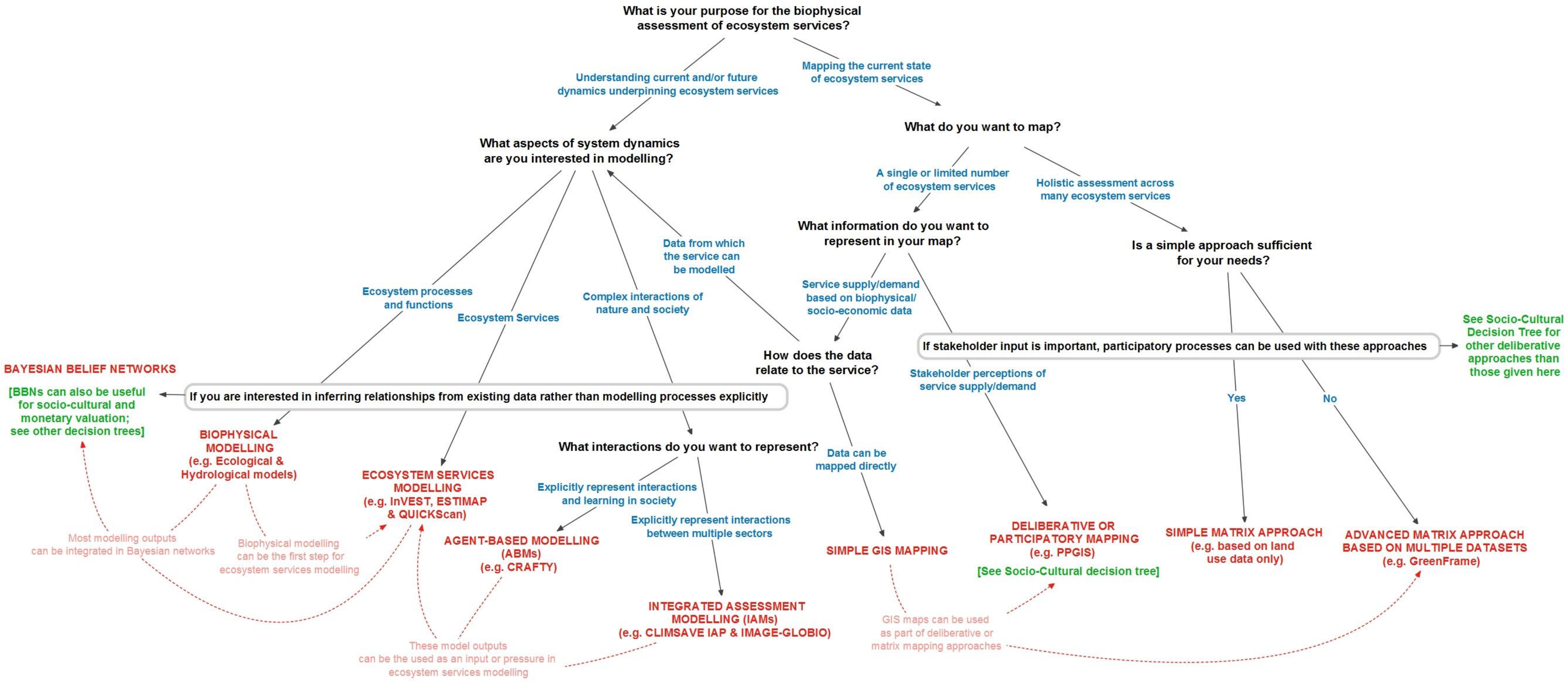
The biophysical decision tree (Figure 5a) provides guidance between different mapping and modelling approaches to ecosystem service assessment. The first question in the tree asks about the purpose of the study, distinguishing between assessments focusing solely on the current state and those wishing to also explore future dynamics. The latter leads to a range of modelling approaches and the former to a range of mapping approaches. Following the modelling branch of the tree, the user is asked about the aspects of system dynamics in which they are interested. If their focus is on specific ecosystem processes then they are led to biophysical models, which include a wide range of different ecological, hydrological and other types of models, whilst if they wish to model a range of ecosystem services they are led to ecosystem service models, such as InVEST, ESTIMAP and QUICKScan. If they wish to understand more complex interactions between nature and human society, then agent-based models may be appropriate if individual or group decision-making behaviour needs to be represented, or integrated assessment models if interactions and feedbacks between multiple sectors such as agriculture, forestry, water and biodiversity need to be represented.

The decision tree also shows that outputs from some types of models (e.g. integrated assessment models that simulate land use change) can be used as inputs to ecosystem service models. Outputs from all model types can also be used in BBNs in addition to other types of data to infer relationships between different system components. It should be noted that only broad types of modelling approaches are indicated in the biophysical decision tree with a few examples as many models exist under each category, which have been reviewed elsewhere (e.g. IPBES, 2016b).

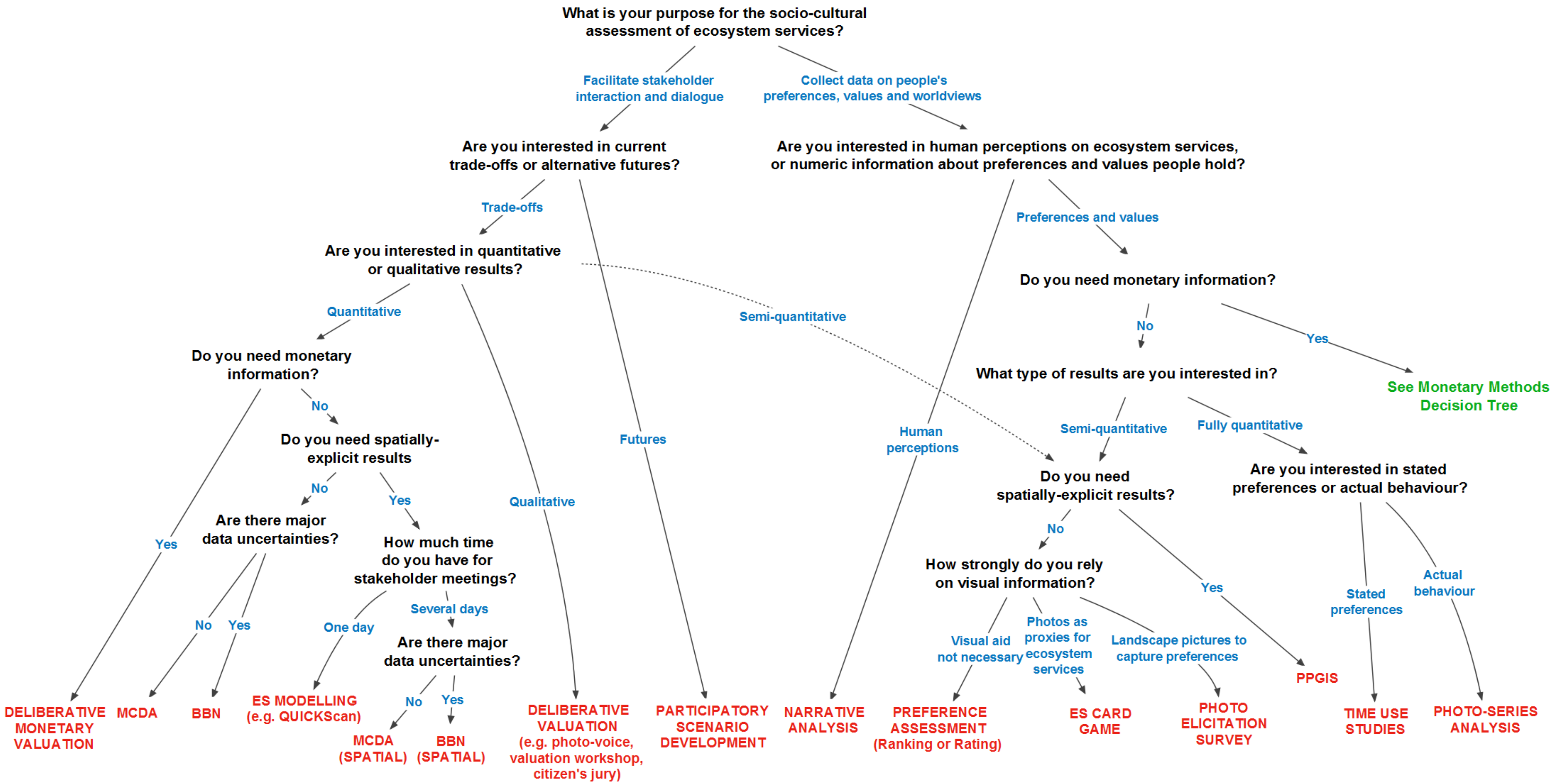
The mapping branch of the biophysical decision tree asks the user what they want to map, either individual or a limited number of ecosystem services, or multiple ecosystem services. The latter leads to matrix-based approaches which vary in their complexity in terms of the number of datasets that are combined to estimate service provision. If the focus is on a single or a few services and stakeholder perceptions of service demand and supply are important, then deliberative mapping is suggested, or if data are available to map a service directly (e.g. for food production) then simple GIS mapping is given as the option. If data is not available to map a service directly then the user is directed to the modelling part of the decision tree. The mapping part of the decision tree also recognises that most of the mapping approaches can be implemented with or without stakeholder engagement and refers the user to the socio-cultural decision tree for further guidance on participatory and deliberative approaches.

Figure 5: Decision trees for (a) biophysical, (b) socio-cultural, and (c) monetary methods.

(a) Biophysical methods decision tree:

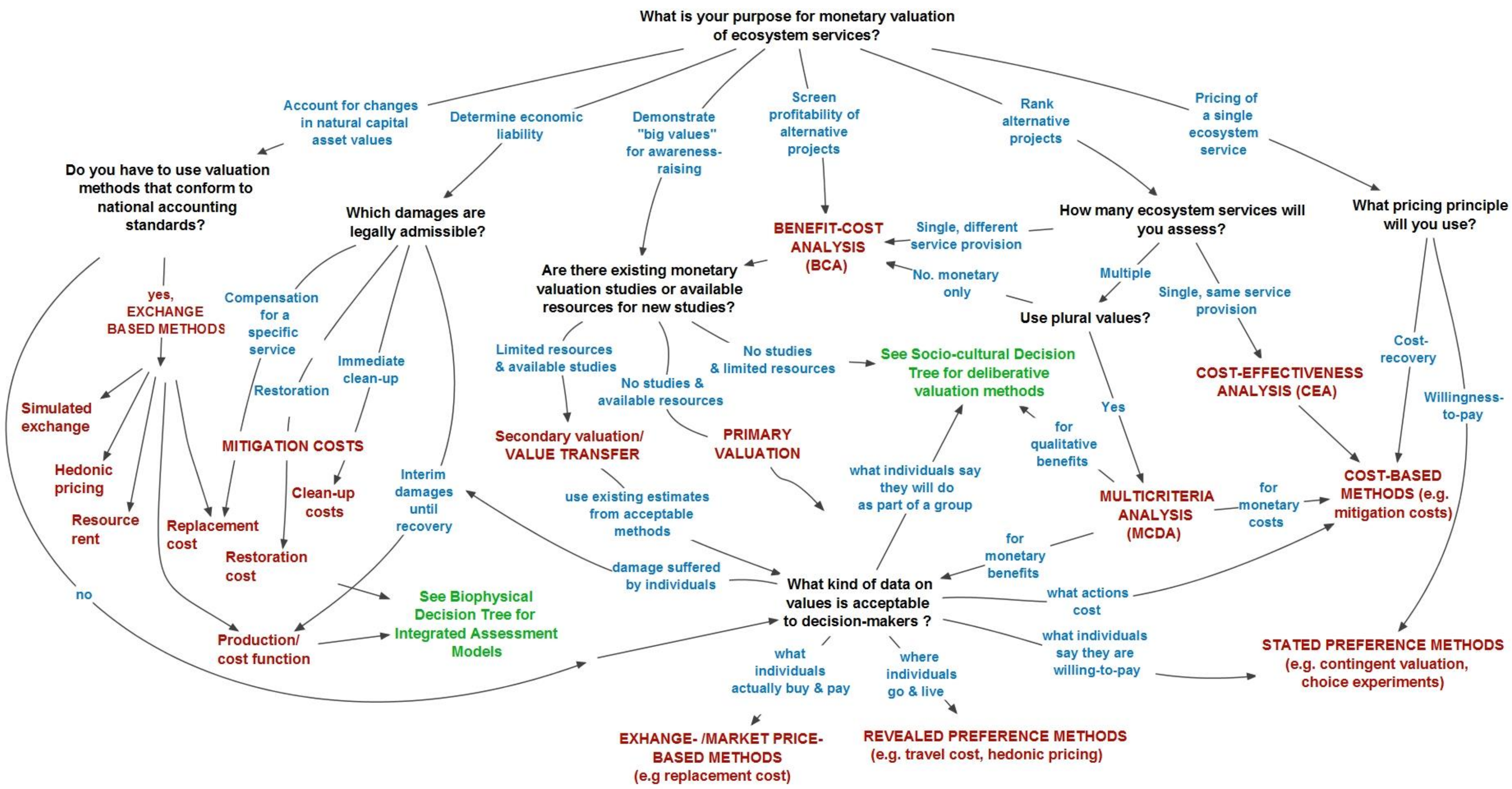


(b) Socio-cultural methods decision tree[5]**:**



[5] As the socio-cultural methods decision tree includes methods that are interdisciplary by nature, some of the techniques are also indicated on other decision trees, and are described among biophyscial (e.g. PPGIS and BBN; Table 3a) or monetary (e.g. deliberative monetary valuation; Table 3c) techniques.

(c) Monetary methods decision tree:



The socio-cultural decision tree (Figure 5b) provides guidance on how to choose between methods that aim to grasp people's perception of ecosystem services. For this decision tree we understand socio-cultural valuation methods broadly, including various approaches, coming from different disciplinary backgrounds that can elicit the (shared) social values of ecosystem services. Socio-cultural valuation of ecosystem services has undergone a rapid development in recent years, but it is still less formalised and more diverse (in terms of ontology and epistemology) than for instance monetary valuation (Santos-Martín et al., 2017). This is reflected by the decision tree, which leads to highly heterogeneous methods through a series of questions, many of them having strong methodological orientation. Beside the empirical experience of OpenNESS case studies, the decision tree took into account relevant literature which categorises socio-cultural valuation methods (IPBES, 2016; Santos-Martín et al., 2017), theorises the process of methodological choice (Vatn, 2009), or analyses empirical evidence beyond OpenNESS (e.g. Gould et al., 2015; Johnson et al., 2012; López-Santiago et al., 2014; Maynard et al., 2015).

The starting question asks about the purpose of the study in terms of the role which stakeholders will play. The two main options suggested are an active, dialogue-like role where study participants are considered as partners, and a more formalised role where study participants are rather seen as data providers. Choosing the first option the user is asked if actual trade-offs or alternative futures are the focus of the study. The option of actual trade-offs leads the user to a number of methods which all embody interactive group processes, but are very heterogeneous in terms of data and time requirements, including how explicit they are in spatial terms and how they handle uncertainties. Such methods include deliberative valuation, BBNs and MCDA. Choosing between them is therefore guided by questions focusing on their key methodological specificities. The option of alternative futures leads the user to participatory scenario development, which can be carried out in different ways depending on the geographical and time scale as well as the number of participants engaged in the study.

Turning to socio-cultural studies with the aim of more formalised (one-way) data collection the user is confronted with two major directions within social scientific research: following a hermeneutic approach that focuses on the understanding of human perceptions of ecosystem services, or applying an explorative-descriptive research strategy that creates numeric data on people's preferences of services. The first direction leads to the family of narrative methods, including interviews, transect walks and field notes of observations, among others. The second direction is further specified according to data requirements (monetary or non-monetary) and the preferred format of the results (level of quantification, spatial explicitness, visuality), which leads the user to socio-cultural techniques, such as preference assessment, photo-elicitation, photo-series analysis and time use studies depending on their methodological needs.

The monetary decision tree (Figure 5c) provides a graphical overview of basic differences in the circumstances where various valuation methods are used. The first question in the tree asks about the purpose of monetary valuation. These high level purposes were defined based on Gómez-Baggethun and Barton (2013) and Laurans et al. (2013). The alternative purposes range from demonstrating values for awareness raising to determining economic liability in a court case. A feature of the tree is that the same method can be used for different purposes – the decision tree leads to the same choice of methods in a number of cases, although the specific design of the method will be fit-for-purpose. Purposes of screening or ranking alternative courses of action lead the user to questions regarding cost-effectiveness (CEA), benefit-cost (BCA) and multi-criteria analysis (MCDA), depending on how comprehensive the impacts of the alternatives are, and whether a single or multiple metrics of value are required. If BCA or MCDA is chosen, the user is asked more detailed questions regarding what kind of individual monetary valuation information would be considered legitimate for supporting decision-making. This question recognises that some types of information may be perceived as more legitimate by stakeholders. The question here is whether the user wants values based on 'what individuals say they will do as part of a group', 'what individuals say they are willing to pay', 'where individuals actually go or live' or what we observe that 'individuals actually buy and pay'. A decision-makers preference for one or other type of information leads to very different individual monetary valuation methods (cost-based, revealed preference, or stated preference).

Another fundamental choice in the decision tree is whether original 'primary valuation' studies can be carried out, or whether 'value transfer' must use existing estimates from another context because of resource or time constraints. The left branch of the decision-tree refers to monetary methods in national environmental economic accounting (SEEA). The SEEA-EEA (UN 2014) provide standards for selecting national accounting methods; they are in a large part based on market prices for estimates of value, and are therefore called 'exchange-based'. Closely related to this branch in the decision tree are valuation methods to determine environmental damages in litigation cases where most of the valuation methods are cost-based. Cost-based methods are based on market-prices, so there is a large overlap in terminology and the types of methods that are used. In general, most valuation methods can be used for more than one purpose, as illustrated by numerous horizontal interlinkages in the decision tree. The decision tree stops with identification of individual methods or method groups. Guidance on selecting and designing specific valuation methods fit-for-purpose is available in a number of manuals (e.g. Bateman et al., 2002; Wood and Beal, 2000; UN, 2014).

4. Discussion

4.1 Method selection considerations

This study aimed to provide comprehensive guidance to researchers and practitioners for selecting different biophysical, socio-cultural and monetary techniques for ecosystem service assessments. Forty-three methods within 26 method groups were offered to the 27 case studies in the OpenNESS project. Case studies selected those methods which they considered met the needs of their decision-making situation guided by its specific land, water and urban context (27 individual methods covering 21 method groups). There is no perfect or correct solution; method selection should not be viewed just in terms of scientific credibility, but should take into account the real-life considerations for applying the ecosystem services concept in practice. The appropriateness of a method for a decision context is defined by Ruckelshaus et al. (2015) according to the different 'impact pathways' for which a method is suited. In OpenNESS, appropriate methods were considered to be those which could be operationalised within a case study context (see Jax et al., this issue). Operational methods address a clearly defined study purpose within constraints on budget, time, data and expertise (Barton et al., this issue). Furthermore, appropriate methods address a range of ecosystem services which are relevant for the study purpose (Jacobs et al., this issue).

The appropriateness of the different methods is reflected in the reasons case studies gave for method selection with decision-oriented reasons related to the study purpose and ecosystem services at stake being highly cited. In addition, methods that facilitated stakeholder participation and deliberation, and which were easy to communicate to a wide range of stakeholder groups, were frequently selected as being appropriate for a case study context. However, this may be (in part) an implicit consequence of the general research set-up within OpenNESS; as each case study research group worked closely with a stakeholder advisory board, so method selection and application had to be transparent and clearly communicated to allow true collaboration with stakeholders. Nevertheless, as discussed by Opdam et al. (2015), participatory approaches to ecosystem service assessment support communication, collaboration and shared visions between different stakeholders for managing ecosystem services, which ultimately supports the operationalisation of the concept.

Pragmatic reasons for method selection were stated less often in the survey to case studies. However, discussions in workshops with case study teams revealed that pragmatic issues were generally the most common reasons cited for NOT using a method. In particular, a lack of experience with the method and problems with data availability were regularly mentioned. The perception of difficulty or complexity of using a method as well as in interpreting the results in a specific context, combined with a lack of time and resources, was also highlighted as a reason for not using a number of the more technical approaches, such as stated and revealed preference methods, time use studies, BBNs, State-and-Transition Models and ecosystem service models like InVEST. Furthermore, the inappropriateness of the method at the spatial scale of the case study was raised as an issue for some methods, such as the broadscale integrated assessment models, deliberative valuation at large spatial scales or the application of the ecosystem service model ESTIMAP at small spatial scales, although the original configuration of ESTIMAP was adapted to fit local case study needs during the project (see Zulian et al., this issue). Finally, the commercial nature of software was seen as a barrier to uptake by some case studies for ecosystem service models such as QUICKScan (although it was made freely available during the course of the project).

This highlights that, for some methods, factors that act as advantages and disadvantages are often two sides of the same coin. The matrix approach, for example, is widely selected for its ease of use, its speed of application and the fact that it is spatially-explicit and can involve stakeholders. However, these strengths are also its weaknesses: it was seen by some case studies to depend too strongly on expert knowledge and simplistic generalisations, which one workshop participant stressed gave it a 'false impression of completeness'. Similarly, BBNs are shown to be well suited for handling uncertainty in a flexible, participatory manner and giving a choice (instead of a singular output). However, they are seen to be difficult to understand and use in a public setting due to the fact that they use probabilities rather than 'real actions'.

This paper examines reasons for selecting individual methods. However, many case studies selected more than one method and combined methods in different ways. Dunford et al. (this issue) explores the different methodological combinations used in the OpenNESS case studies. The authors discuss six different ways in which methods were combined including: (i) direct transfer of data between methods; (ii) direct transfer of ideas, concepts and learning between methods; (iii) hybridisation of methods; (iv) customisation of methods; (v) cross-comparison of methods; and (vi) direct transfer of methods between different issues. Therefore, guidance based on selecting a single method in isolation should recognise that methods are not completely independent of each other, and that there may be advantages from combining methods to address a case study purpose. This is especially true if a user would like to cover a full range of plural values attributed to ecosystem services, as most individual methods are not capable of grasping multiple value types without combining them with others (Jacobs et al., this issue).

4.2 Decision trees as a form of guidance

Decision trees were selected as a way of structuring the information gained from the case study surveys, workshops and the analysis of the key features of the methods. This was because people tend to find decision trees easy to understand; the approach is often described as a 'white box' where each nodal split is transparent with no hidden assumptions (Rokach and Maimon, 2005). They were thus thought to be a relatively simple way of presenting and guiding a user to arrive at a decision related to ecosystem service method selection. Nevertheless, the process of developing and testing the decision trees revealed several limitations. First, complexity can be difficult to represent in decision trees as once the hierarchy becomes large the approach becomes inefficient, time-consuming and difficult to represent (Nayab, 2011). This is the reason why three inter-linked decision trees were created rather than a single overly complicated tree. A user can start with any of the three decision trees depending on the context of their case study and is shown where there is permeability between the three broad methodological groups within each tree. We originally attempted to develop a master decision tree that would point a user towards a particular method group decision tree, but this proved either extremely complex in terms of the number of reasons that may be relevant, or very obvious, i.e. if monetary values are important start with the monetary methods decision tree. Hence, other ways of guiding a user to a particular decision tree or order of use were considered including the development of introductory material and their integration with other guidance tools (see section 4.3).

Second, decision trees are highly linear in their approach with nodes always being approached through the same sequence (Quinlan, 1990). Feedback from our workshops showed that users were sometimes challenged to go down routes that they did not want to and that they would prefer different ways to get to the same method if this was applicable. This non-generalisation of fixed routes through a decision tree was also observed by Grêt-Regamey et al. (2016). Third, decision trees are usually discrete requiring a binary choice to be made at each stage (Nayab, 2011). Case studies found a bimodal structure problematic, so the decision trees were revised to represent a multi-modal structure where possible. Despite these limitations, the case study teams overwhelmingly agreed that the decision trees were useful in capturing and structuring the decision process for selecting methods, particularly if they are used with the qualification that they present a simplified overview compared to the real context of operationalising the ecosystem service concept in a specific decision context.

The decision trees were based on empirical data from the OpenNESS case studies. These case studies were mainly located in Europe, but they were set up in highly variable contexts to encompass a wide range of socio-cultural, ecological and policy contexts. The four non-EU case studies of OpenNESS increase the applicability of the decision trees outside of Europe, although we recognise that they are probably not sufficient in number or variety to assume that the decision trees are widely applicable throughout the globe. Furthermore, most case studies in OpenNESS were landscape level or local scale studies, so the choice of methods largely reflects experience with local to regional scale assessment and valuation choices.

To overcome these potential limitations and ensure that the decision trees were generic enough to apply to other cases and regions outside of the OpenNESS project, their design was based on an iterative process that combined the empirical findings from the case studies with the expert judgement of method experts. In addition, this expert knowledge was supplemented with a comprehension of the wider literature to increase the robustness of the decision trees. Nevertheless, there are conceivably a number of different starting points for method selection. Those presented here are representative of the research design of OpenNESS. As such, the decision trees are not meant to be prescriptive, but to provide support in screening methods, in order to accomplish more integrated assessment and valuation of ecosystem services. They provide benchmarks or frameworks to think systematically about factors affecting method choice, with a view to improve study design in future projects. In particular, decision trees helped the case study researchers identify their 'post-rationalisation' of method choice, adapting the ends to the means (see Jacobs et al. this issue). Furthermore, thinking in terms of decision trees raises awareness about the context and path-dependency of the outcomes of ecosystem service assessment and valuation.

The decision trees are also a useful illustration of integrated valuation, which recognises value plurality (Gómez-Baggethun et al., 2014). They consider the different ways values of ecosystem services are 'framed' by the decision-making context and the choice of method (see also Jacobs et al., this issue). Broad contexts for valuation include explorative, informative, decisive and technical design purposes (see Table 3c) and Barton et al. (this issue). As such, the decision trees tell the story that valuation methods are value articulating institutions (Vatn, 2009). Values are articulated by the decision context conditioning the choice of methods, and then by the specific design of how the method itself articulates/elicits values. While the same method can be used for different purposes its fit-for-purpose design means that values are not easily transferable across purposes. The monetary decision tree is also a useful reminder of the context specificity of economic values and a caution to transfer of value estimates (Johnston et al., 2015) between decision contexts (and locations).

4.3 Integration and operationalisation of multiple forms of guidance

Further improvements to the decision trees are planned through their implementation online within the Oppla web platform for ecosystem services and nature-based solutions (www.oppla.eu). Feedback from case studies showed that being able to view the full decision tree at once was useful as well as being taken through each tree as a step by step online tool. Part of this further development of the decision trees as an online guidance tool will also include adding tooltips to more fully describe the questions within the trees, providing factsheets for each method listed at the endpoint of a tree, and adding information on potential method combinations or alternatives. This latter point will enable the linkages between the different decision trees and the biophysical, socio-cultural and monetary methods included within them to be better highlighted than currently.

Introductory material will also be developed that describes the overall aim and structure of the decision trees. For example, it is beneficial for users to reflect on the purpose of their case study and its local context before making use of a decision tree. Other forms of guidance within Oppla can help with this task, including the ”Ask Oppla” question and answer service, the Oppla Case Study Finder where users can search for cases with a similar decision context or in a similar location, the Oppla marketplace which contains many searchable tools, methods and products, and the Oppla Community where Oppla members can find others with common interests or issues.

Integration of the decision trees within Oppla will also enable users to find methods through different entry points or guidance tools. This recognises that Oppla members are likely to have a wide range of backgrounds and different purposes for ecosystem service assessment. Hence, a single guidance tool is unlikely to fit all needs. Two other forms of guidance tools are being developed and tested to sit alongside the decision trees. The first is the Ecosystem Service Assessment Support Tool (ESAST), which has been designed to provide guidance to users who are new to ecosystem services and need assistance in designing an effective assessment process. It can also assist experienced users in providing detailed information about different concepts, methodologies and links to case study information. The ESAST is divided into five core steps that can be carried out in an iterative fashion: (i) setting the scene; (ii) identification of ecosystem services; (iii) biophysical assessment; (iv) valuation; and (v) put into practice. Each step provides the user with the rationale, objective and the expected outcome of the step as well as crosslinks to resources, illustrative real-world cases, and tools and methods to be used in that stage of the assessment process. The decision trees will be directly accessible from the biophysical assessment (biophysical decision tree) and valuation (socio-cultural and monetary decision trees) steps within the ESAST.

The second guidance tool, which will also be cross-linked to ESAST, addresses the problem of decision trees having a rigid sequence of selection questions. A BBN classification model (http://openness.hugin.com/oppla/ValuationSelection) has been constructed that applies a set of requirements and user needs flexibly, in any combination and order the user desires. The BBN is populated with 51 methods described using 26 method requirements/user needs, collected from ecosystem service assessment and valuation researchers and practitioners active in the OpenNESS and OPERAs projects. The BBN method selection network can be used in two ways. First in “Method selection support mode” where a user selects method characteristics that are relevant for their context from the categories: “Context”, “Scale”, “Data”, “Ecosystem Services”, “Resources” and “Total

Economic Value". The portfolio of tools that are relevant for those conditions are then shown online. Second in "Method description mode" where a user opens an interface to the BBN allowing the user to inspect the characteristics of each particular method. Where the characteristics of the methods are uncertain a probability distribution is displayed. The BBN method selection tool provides a further step beyond the decision trees for users wishing to explore method possibilities and constraints in more detail. It enables users to see how their filters affect the offered choice of methods, and provides users with more than one suggested method recommendation that fits their needs.

The combination of the decision trees with these other guidance tools within Oppla will provide a novel and accessible set of interlinked resources that researchers and practitioners can utilise in the operationalisation of the ecosystem service concept in real-world case studies. This will build a valuable knowledge base that can be shared, further tested and improved over time with the extensive Oppla community to advance practical applications on natural capital, ecosystem services and nature-based solutions.

5. Conclusions

A set of decision trees has been developed to structure and guide the process of selecting biophysical, socio-cultural and monetary methods for ecosystem service assessment. The trees are based on an assessment of reasons given for method selection in 27 case studies which could be broadly categorised into stakeholder-oriented, decision-oriented, research-oriented and method-oriented considerations. This information was combined with a characterisation of the key features of the different method groups by the method experts that affect the applicability of the methods in different decision contexts. The decision trees were found to be useful as frameworks for supporting a more systematic reasoning about method selection by providing a transparent tool for structuring and communicating information needed to make method choices. Integrating the decision trees with other guidance tools provides a more flexible support system that is better able to cover the varying demands and constraints of researchers and practioners. This should lead to improved design and implementation of future ecosystem service assessment and ultimately to better decision-making on ecosystem services in practice.

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Selecting methods for ecosystem service assessment: A decision tree approach

Supplementary Materials

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Table S1: Details of the OpenNESS case studies.

Sustainable urban management case studies:
1. Operationalising ecosystem services in urban land-use planning in Sibbesborg, Helsinki Metropolitan Area, Finland
2. Landscape-ecological planning in the urban and peri-urban areas of Trnava, Slovakia
3. Valuation of urban ecosystem services in Oslo, Norway
4. A Green Infrastructure strategy in Vitoria-Gasteiz, Spain
5. Mapping ecosystem services to inform landscape planning in the Barcelona metropolitan region, Spain
Management of forests/woodlands
6. Operationalising ecosystem services in regional and national forest management planning in the multifunctional landscape of the French Alps
7. Forest bioenergy production in Finland
8. Forest management in the Carpathian Mountains, Romania
Management of mixed rural landscapes
9. Bioenergy production in Saxony, Germany
10. Improved, integrated management of the natural resources within the Cairngorms National Park, Scotland
11. Ecosystem services in the multifunctional landscape of the Sierra Nevada, Spain
12. Tools for investigating biodiversity offsetting in Warwickshire, England
13. Supporting sustainable land use and water management practices in the Kiskunság National Park, Hungary
14. Reintroducing green corridors in the agricultural land of the Province of Limburg, Belgium
15. Planning with Green Infrastructure in five linked cases
Integrated river basin management
16. Nature-based solution for water pollution control in Gorla Maggiore, Italy
17. Quantifying the consequences of the European water policy for ecosystem service delivery at Loch Leven, Scotland
18. Operationalising ecosystem services for an adaptive management plan for the Lower Danube River, Romania
19. Integration of ecosystem services in the planning of a flood control area in Stevoort, Belgium
Coastal area management
20. Incorporation of ecosystem services in maintenance of the traditional cultural landscape of Doñana in south-west Spain
21. Ecosystem services in coastal management, Wadden Sea, the Netherlands

22. Operationalising ecosystem services in the Sudoeste Alentejano e Costa Vicentina Natural Park, Portugal
23. Ecosystem service mapping in Essex, England
Commodity export dominated areas in developing countries
24. Participatory biodiversity management for ecosystem services in Bankura and Sundarbans, India
25. Operationalising ecosystem services for improved management of natural resources within the Kakamega Forest, Kenya
26. Retention forestry to improve biodiversity conservation and ecosystem services in Southern Patagonia, Argentina
27. Biofuel farming and restoration of natural vegetation in the São Paulo region, Brazil

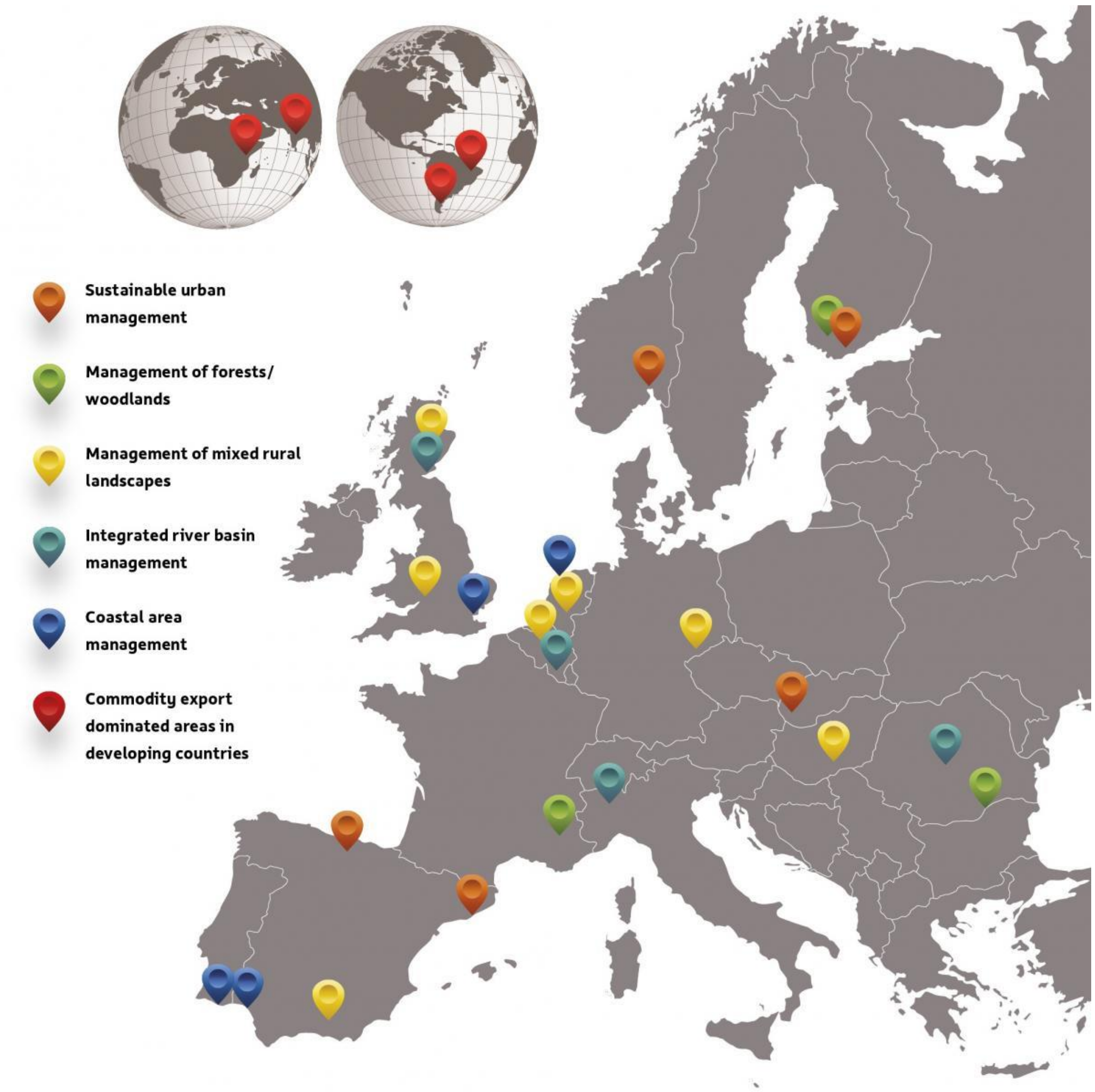

Figure S1: Map of the OpenNESS case studies showing the different management contexts.

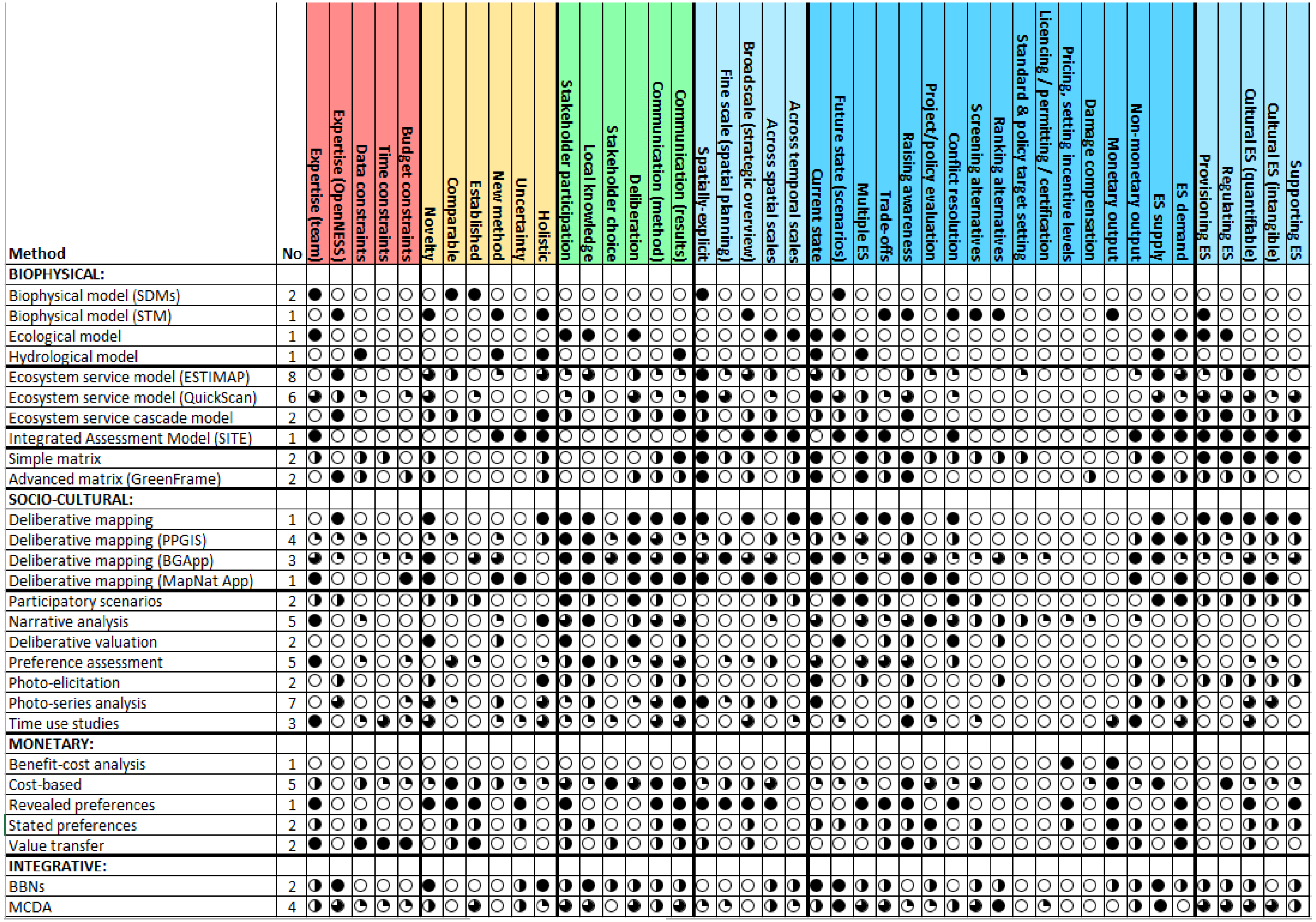

Figure S2: Reasons for ecosystem service (ES) assessment method selection summarised by individual methods. Pie charts indicate fraction of case studies indicating the reason as a major consideration for method selection: full black = 100%; full white = 0%; inbetween values shown in fractions of 25%. No = number of case studies applying the method and completing the survey. Colours show the reason categories are explained in Figure 3.