OpenNESS

Operationalisation of Natural Capital and Ecosystem Services

Integrated assessment and valuation of ecosystem services

Guidelines and experiences

From concepts to real-world applications
www.openness-project.eu

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Executive Summary

As the ecosystem service concept has become more widely recognised, so the number of biophysical, socio-cultural and monetary methods available to assess ecosystem services has increased. There is relatively little guidance on how to select and combine these methods into **hybrid approaches** that address policy purposes. Based on experiences from 27 case studies with 33 different assessment and valuation methods in the OpenNESS project, this report aims to fill some of that gap in science and practice.

This report provides a number of tools that practitioners can use to plan, commission and evaluate integrated assessment and valuation studies of ecosystem services. The report starts by providing a **rapid guide** to commonly used biophysical, socio-cultural and monetary methods. A number of different 'bottom-up' and 'top-down' approaches to **selecting methods fit-for-purpose** are provided. OpenNESS method experts have developed detailed **fact sheets** on each method in the report appendix and available online at http://www.oppla.eu/.

«Plural valuation is do-able»

Network diagrams show the reader which assessment and valuation methods are most related and complementary. **Decision trees** provide a stepwise framework for scoping and integrating assessment and valuation studies which identifies the best method that is suitable to a specific purpose. **Method consideration matrices provide** a detailed list of several dozen method selection criteria, derived from case study experiences. **Selection criteria tables** are further specified for each suite of biophysical, socio-cultural and monetary valuation methods. An **online method selection tool,** develped in collaboration with the Opera's project, demonstrates how combinations of study purposes, considerations and constraints can be used to identify **portfolios of methods**. Managers can use these method selection tables, matrices decision-trees and online tools to scope what is possible in their particular decision context. The material is also useful for specifying the terms of reference for ecosystem assessments.

"Start ecosystem service assessments by identifying study purpose"

The report then shows how **real world experiences** in the OpenNESS case studies lead to the innovation and development of hybrid assessment methods that better addressed the particular **needs of local decision-makers**. The report summarises which combinations of biophysical modelling, mapping-modelling, expert-based, participatory, socio-cultural, monetary and integrative approaches were more likely to be combined in the case studies. We provide detailed examples using **process diagrams** to show how case studies scoped the study purpose, adapted and combined different method types. The real world process of applied research was non-linear and iterative, time consuming, but also creative.

These examples can provide funders of applied research at EU and national level with a wider perspective on how to support innovative development of ecosystem service assessment methods.

Real-life examples of method application and hybridisation show managers and researchers

that the complexities of ecosystem service assessments require research projects with creative arenas and that are sufficiently flexible to hybridise methods opportunitically as data is revealed and **decision windows** arise. The report shows that ecosystem service

« Scope the problem and select assessment and valuation methods using different frameworks »

assessment are very do-able in such project environments.

Ecosystem assessments and valuation in the OpenNESS case studies revealed **plural values** that are context specific. The advantages to revealing these values is greater local buy-in to assessment results and policy findings. The flip side of value plurality is the need for standardisation and comparability at national and international levels, for example in ecosystem accounting. The report provides guidance on selecting a set of valuation methods which is both appropriate and realisticallly applicable to elicit the diversity of ecosystem service values. We argue that planners should see **biophysical assessment methods** playing the same role as valuation methods in decision-support by identifying importance**.** They can be comparable in terms of decision-relevant information content to
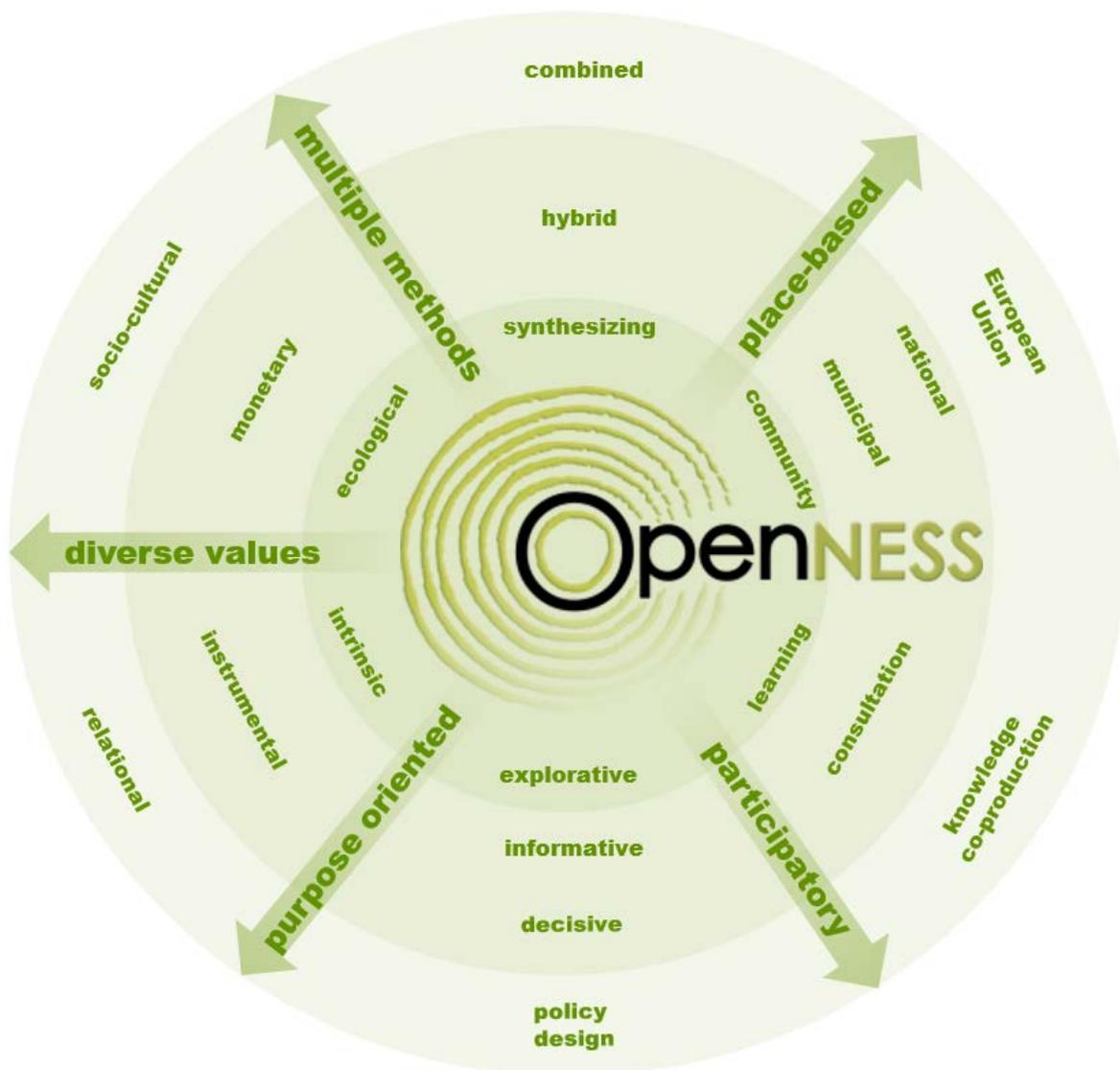
Figure 1 An OpenNESS approach to valuation of ecosystem services and natural capital

socio-cultural valuation methods, and the the more familiar monetary valuation methods. OpenNESS case study researchers have found that adopting this **value-plural position** provided them with a wider repertoire of approaches to address stakeholder decision-support needs and achieve wider buy-in.

We show statistically how biophysical, socio-cultural, monetary and synthesising methods complement oneanother in addressing the **key value dimensions** identified by the Intergovernmental Panel on Biodiversity and Ecosystem Services, namely instrumental, relational and intrinsic values. The report demonstrates the old adage that "there are horses for courses" – we show that a value plural approach provides possibilities to find combinations of inexpensive methods that address the three key value dimensions in local case study contexts.

« What kind of valuation is worth it? Consider the information costs and the specific purpose»

Next we provide a framework for viewing ecosystem service appraisal methods as **value articulating institutions.** The framework provides support for treating biophysical, socio-cultural and monetary assessment methods as **methods to identify importance** – in other words as valuation methods. With all this opportunity for plural valuation of ecosystem services, why do numerous literature reviews find that ecosystem service assessment and valuation studies are so rarely used for decision-support? The last chapter of the report answers this question by discussing practical **constraints on ecosystem service assessment**.

The operationalisation of plural and integrated valuation is challenged by the time and resource required to support decision-making. There is often a mismatch between the time taken to produce integrated valuation outputs and the different administrative and hierarchical levels of public and private sector decision-making cycles.

« Biophysical assessments can play the same role for decision-support as valuation methods»

The report provides several conceptual frameworks help practitioners think about the **purpose and decision context** when designing ecosystem service assessments.   We show how the ecosystem service cascade framework can be used as a framework for plural valuation, based on **iteration and learning.** The ecosystem service cascade framework is also interpreted in terms of **uncertainty** involved in integrated assessment of complex socio-ecological systems.   The frameworks presented in the final chapter of the report serve as reminders to practitioners to account for uncertainty in integrated assessment and consider **costs of information**.

Allowing for iteration and learning in study design is an important way of tackling the complexity and uncertainty inherent in ecosystem service assessment.   Overall, the report delivers strong recommendations to start ecosystem service assessment and valuation by identifying study purpose, and provides a detailed classification to aid in scoping of studies and selecting methods.

«Use a greater diversity of valuation methods - engage more stakeholders and improve buy-in »

Introduction

Given the plethora of ecosystem service appraisal methods, guidance is essential to help researchers or practitioners who are new to the field select and test relevant approaches that take account of their needs and constraints. Most guidance documents provide a limited selection of tools or methods which can be searched or filtered. This report aims to provide a more comprehensive guidance for coordinated selection of different biophysical, socio-cultural and monetary techniques for ecosystem service appraisal. The report offers many *experiences* of how biophysical, socio-cultural and monetary methods were combined into *hybrid approaches* to meet specific needs of local stakeholders. The report contains a collection of frameworks and guidelines that offer complementary perspectives on *integrated assessment and valuation*. Recommendations are based on application of ecosystem service appraisal methods in 27 case studies covering different land, water and urban decision-making contexts.
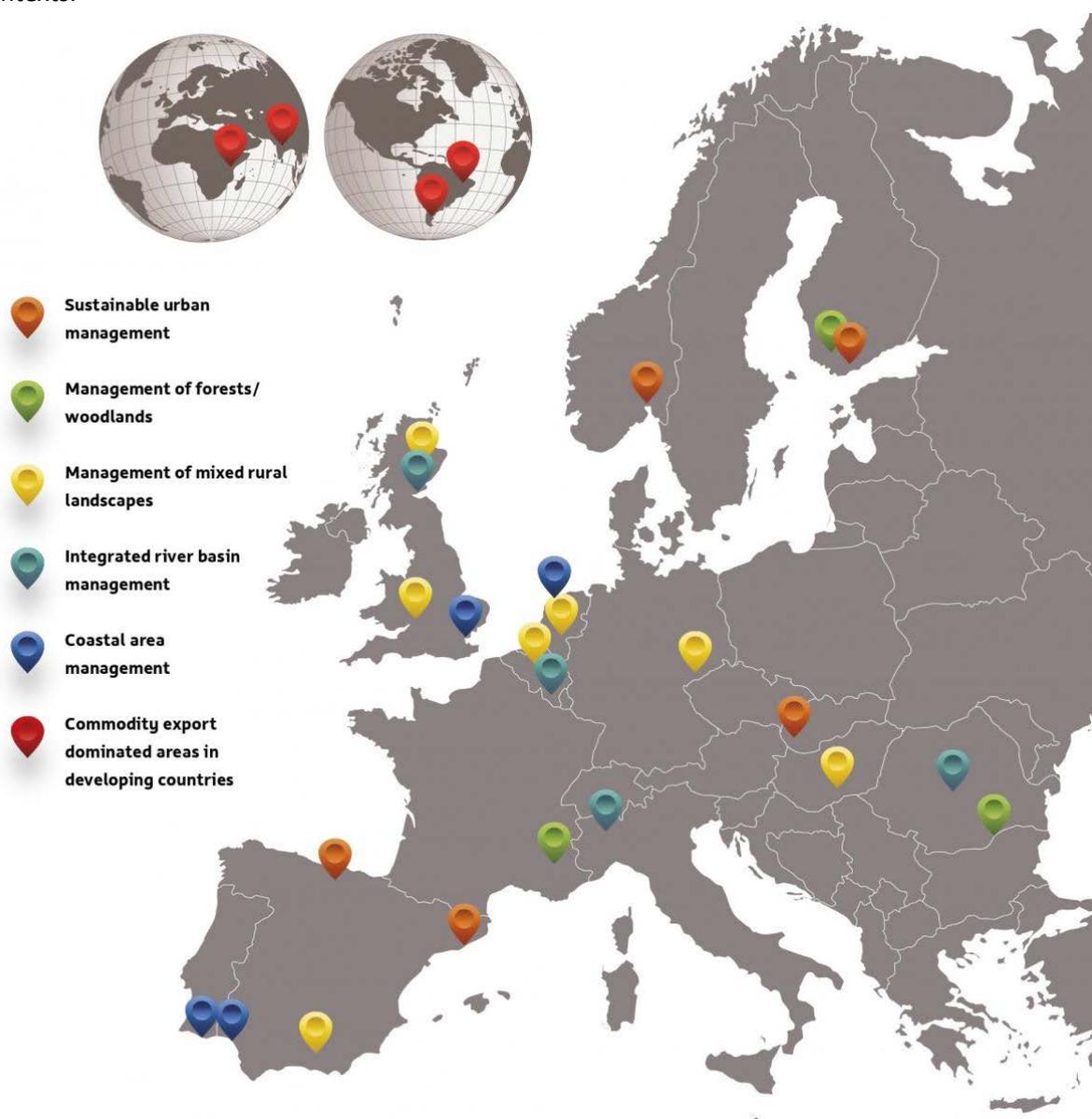
Map 1 OpenNESS case study sites

Case studies focused on operationalising the ecosystem service concept in different management contexts, including sustainable urban management, management of forest/woodlands, management of mixed rural landscapes, integrated river basin management, coastal area management, and commodity export management.

Whilst it is clear that methodological plurality is a necessary reality of ecosystem service appraisal, particularly at local to regional levels, this clearly provides significant challenges for contexts that have a need for comparable, standardised approaches to inform policy at national or international levels. This report also demonstrates how a large research project, with many and varied case studies, can carry out a self-evaluation of operationalisation.

The report is structured as follows:

Chapter 1 addresses the challenge of understanding the requirements of different decision-making contexts and what is gained in moving from simple to more complex ecosystem service assessment approaches. The chapter summarises 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. The chapter reviews findings from a survey of the reasons why case study teams selected particular methods. We discuss 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. Pragmatic reasons such as available data, resources and expertise are also discussed. Based on survey findings and analysis of the key features of different methods, a set of linked decision trees are presented. These aim to provide guidance to researchers and practitioners in choosing ecosystem service assessment methods that are suitable for their context.

Chapter 2 draws further on an analysis of OpenNESS case studies, to detail both the diversity of ways that biophysical, socio-cultural and monetary approaches were combined in practice, and the reasons driving selection in different contexts. The chapter synthesises these experiences to provide take-home messages that illustrate where, and in what contexts, different methodological combinations were used. The chapter provides suggestions for those working in ecosystem service assessment drawn from experience of the case studies.

Chapter 3 evaluates the suitability of 21 valuation methods for 11 value types and assesses the methodological requirements for their operationalization. We discuss how different valuation methods have different suitabilities to elicit diverse value-types. We discuss how some methods are more specialized than others, as well as method blind spots. The chapter assesses methods coverage of intrinsic, relational and instrumental value dimensions. We demonstrate that performing integrated valuation does not necessarily entail more resources. The chapter provides further guidance on selecting a complementary set of valuation methods in order to develop integrated valuation in practice.

Chapter 4 focuses on how study purpose, information costs and stakeholder characteristics co-determine uptake and influence ecosystem service (ES) appraisals in governance. We discuss three complementary conceptual frameworks for understanding the integration challenges of ES appraisal

methods – a rational actor view of the ES cascade, ES appraisal as value articulating institutions, and cumulative uncertainty in integrated valuation. Based on the frameworks we formulate and test an information cost hypothesis to explain the relative frequency of different study purposes across broad classes of ES appraisal. We evaluate the hypothesis using survey data from a survey of OpenNESS case study coordinators and stakeholders in 26 case studies involving 80 ecosystem services appraisals. We discuss the extent to which ES appraisals were applied for decision-support. We also use the conceptual frameworks to discuss the operational challenges observed by case study stakeholders. Finally, the chapter makes some recommendations on future research on integrating plural values in ecosystem services appraisal, emphasising the importance of information cost.

The final section of the report contains **Method Fact Sheets** for the most frequently applied ecosystem service appraisal methods in OpenNESS, and introduces an online **method selection tool**.

Chapter 1 - Selecting methods for ecosystem service assessment: A decision tree approach

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Chapter overview

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. A key challenge in method selection is to understand the requirements of different decision-making contexts and what is gained in moving from simple to more complex approaches. This chapter addresses this challenge 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.

Chapter Keywords

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

Published article

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., in press; Ruckelshaus et al., 2015). 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 and spreadsheet approaches (e.g. Burkhard et al., 2012; Kopperoinen et al., 2014), modelling ecosystem services such as InVEST (Sharp et al., 2016), E-Tree (Baró et al., 2015) or ESTIMAP (Zulian et al., in press);

(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. Proctor and Drechsler, 2006; Randhir and Shriver, 2009; Saarikoski et al., 2016), and photo-elicitation surveys (García-Llorente et al., 2012a);

(iii)   *monetary methods* for estimating economic values for services, such as stated preference methods (Bateman et al., 2002) using contingent valuation (e.g. Gürlük 2006) and choice modeling (García-Llorente et al. 2012b), revealed preference methods such as travel cost method (e.g. Langemayer et al., 2016; Martín-López et al., 2009; McConnell, 1985) 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 new to ecosystem service assessment 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,

- Royal Society for the Protection of Bird's (RSPB) Guidance Manual for Assessing Ecosystem Services at Natura 2000 sites (McCarthy and Morling, 2014);
- Global Reporting Initiative's (GRI) Approach for Reporting on Ecosystem Services (GRI, 2011);
- Ecosystem Services Guidance for the Oil and Gas Industry (IPIECA/OGP, 2011);
- Convention on Biological Diversity's (CBD) Best Policy Guidance for the Integration of Biodiversity and Ecosystem Services in Standards (CBD, 2013);
- Food and Agricultural Organisation's (FAO) Policy Support Guidelines for the Promotion of Sustainable Production Intensification and Ecosystem Services (FAO, 2013);
- Business and Biodiversity Offsets Programme (BBOP) Biodiversity Offset Cost-Benefit Handbook (BBOP, 2009);

- 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; Pascual et al., 2016; Seppelt et al., 2012) and some guidance documents which 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, 2015).

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:
- Ecosystem Knowledge Network's Tool Assessor[1]
- NEAT Tree Short Tool Reviews[2]
- 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 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. Finally, Pullin et al. (2016) analysed the strengths and weaknesses of knowledge synthesis methods that can be used to inform biodiversity and ecosystem services policy or management.

In this chapter 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

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

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 chapter 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 demands within the Oppla online platform (www.oppla.eu) for ecosystem services and nature-based solutions.

2. Method

The ecosystem service assessment methods were implemented and tested in 27 case studies as part of the EU-funded OpenNESS project. The case studies cover varying geographical regions and extents. 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 management, management of forest/woodlands, management of mixed rural landscapes, integrated river basin management, coastal area management, and commodity export management. Further information on the case studies is available in the OpenNESS case study book (Wijnja et al., 2016) and Dick et al. (in press).

Thirty three methods were considered by the case studies as possible options for application. 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. Classifying methods into broad groups can be difficult as some methods are integrative by nature and span the groupings. Figure 1.1 illustrates some of the key inter-linkages between the broad method groups. 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 1.1) 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 Chapter 2 and Dunford et al. (in press), whilst this chapter focuses on the selection of individual methods while acknowledging this simplifying assumption. An overview of the broad method groups and some examples of specific methods within them is given in Table 1.1.

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 1.2. 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.

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) (See Method Fact Sheets at the end of this report). 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 was followed by a group exercise at a project meeting where case studies compared their reasons for method selection and drafted simple schematics illustrating their decision process for method selection. An expert group representing different methodological expertise then consolidated these outputs to create draft decision trees for biophysical, socio-cultural and monetary methods.
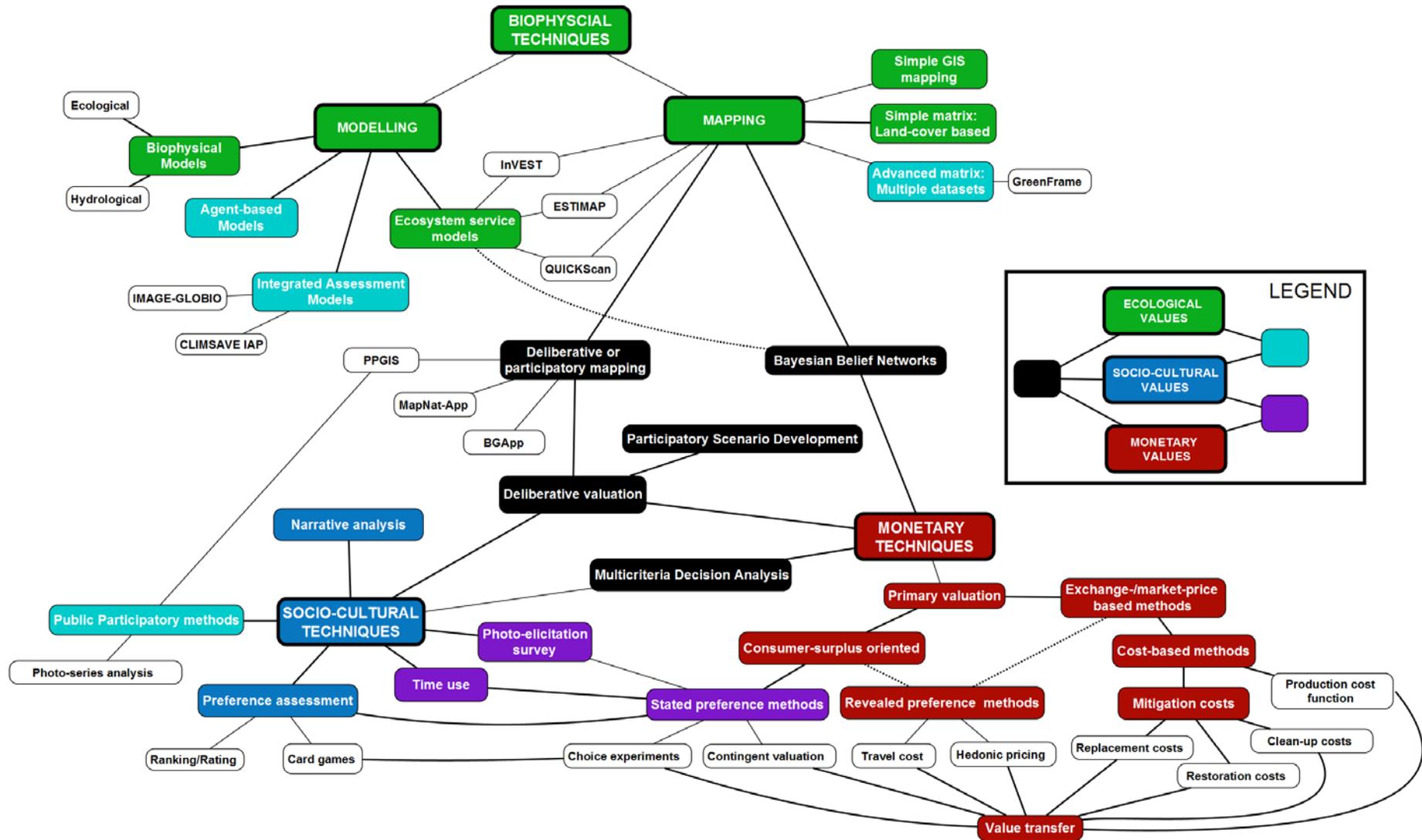
Figure 1.1: Schematic illustrating broad method groupings and the inter-linkages between them. Broad method groups are colour-coded by the types of values they encompass (individual or combinations of value types). Boxes with white background represent examples of specific methods.

Table 1.1: *Overview of the ecosystem service assessment methods applied in the OpenNESS 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., in press); (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); and (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).
Agent-based modelling[4]	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) IMAGE-GLOBIO, a global model which simulates past, present and future impacts of human activities on biodiversity and ecosystem services (Alkemade et al., 2009); and (ii) 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 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.

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[4] Not applied in the OpenNESS case studies, but included here to enable more comprehensive guidance.

Method	Overview
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).
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).
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).
ES card game	The ecosystem services card game is a method developed to capture the sociocultural values related to ecosystem services through combining photo-elicitation (see below) with a rating exercise.
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).

Method	Overview
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 (below). 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).
Cost-based methods /Mitigation costs	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.
Time use studies	This method is an innovation of the conventional stated preference techniques taken from the contingent valuation approach. 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).
Resource rent[4]	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)
Simulated exchange[4]	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[4]	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).

Method	Overview
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., in press). 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).

Aug 2013	Questionnaire to case studies: interests, expertise, data
Oct 2013	Workshop to match case studies and methods
Jan 2014	Guidelines for methods written
Mar 2014	Project meeting: Training sessions/method clinics
Nov 2014	2-day method training workshop
Dec 2014	Survey of reasons for method selection
Apr 2015	Project meeting: Session on reasons for method selection and drafting schematic of decision process for method selection
Summer 2015	Drafting of decision trees
Oct 2015	Project meeting: Multiple sessions to test draft decision trees with case studies
Jun 2016	Follow-up survey of reasons for method selection
Summer 2016	Revision of decision trees

Figure 1.2: *Timeline of method selection process.*

The draft decision trees were 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. Finally, the expert group 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 includes reasons related to the overall purpose of the case study and the ecosystem services at stake.

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, how easy the method was to apply, the amount of time a method took to apply, and the resources required to apply a method (in terms of person-months). 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; whether it was concerned with specific services or groups of services (i.e. cultural, regulating or provisioning) or in multiple ecosystem services and the trade-offs between them, and 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 Chapter 4 (and Barton et al., in press). 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 1.3 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, incentive levels or damage compensation being rarely cited (4 to 8%). Within the decision-oriented category the ecosystem service of interest 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, and the expertise available for implementing a method.
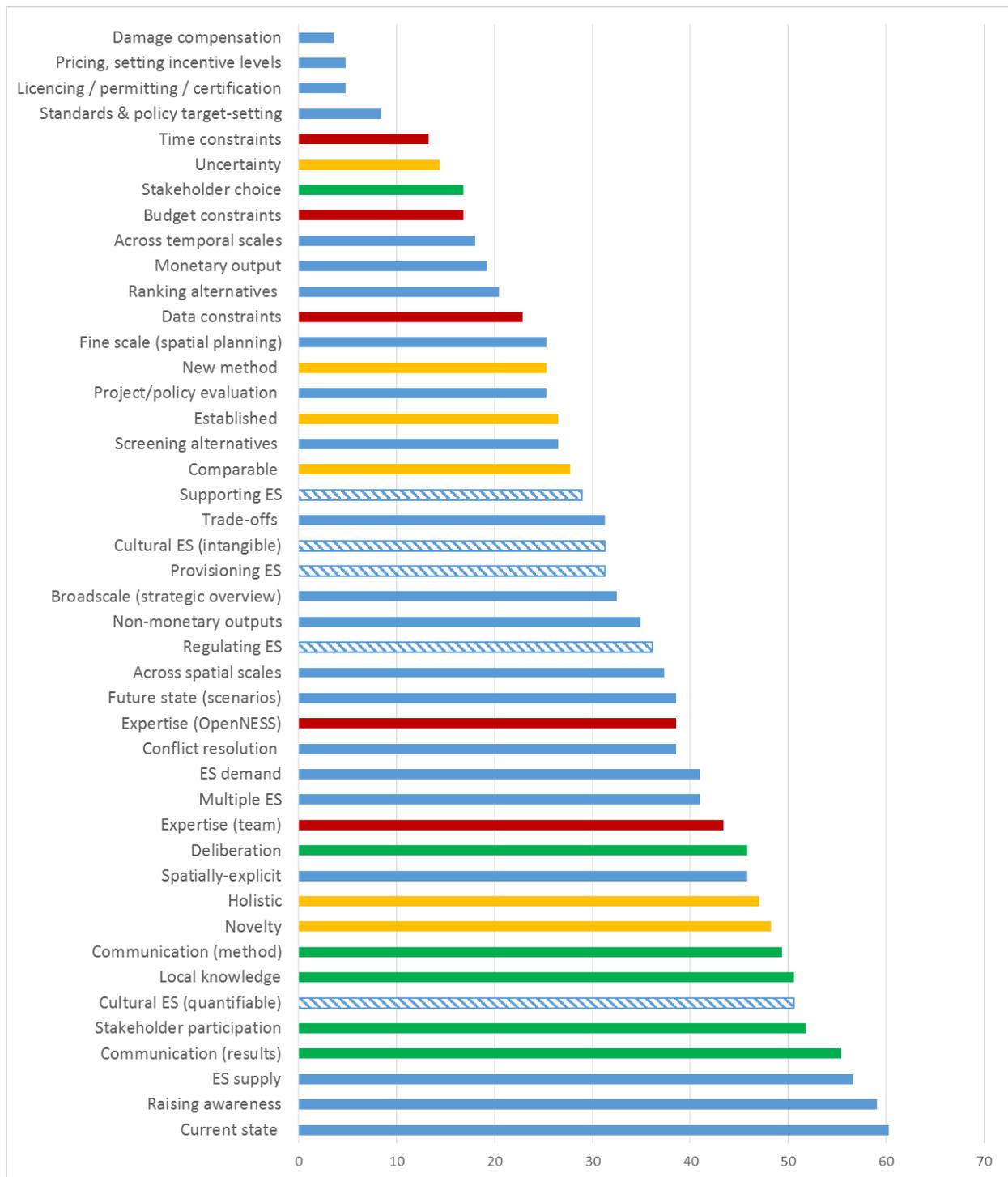
Figure 1.3: *Percentage of times a reason was given as being a major consideration for ecosystem service (ES) method selection across all case studies. Colours show the categories of the reasons: red = methodology-oriented; yellow = research-oriented; green = stakeholder-oriented; blue solid = decision-oriented (purpose-related); and blue hatched = decision-oriented (ecosystem service-related).*

Looking at the considerations by method type highlights some interesting patterns (Figure 1.4). Five different types of biophysical model were applied in the case studies, each of which is associated with slightly different reasons for its use. However, some broad patterns can be seen with respect to the

strong scores for research-oriented reasons, such as novel and holistic approaches, and for methodology-oriented reasons, such as a need to have expertise in the case study team. Key decision-oriented reasons included approaches that could be used to assess future ecosystem service supply (e.g. through scenarios) as well as current ecosystem service supply, and a focus on provisioning and regulating services. Spatial issues varied by model type with some being spatially-explicit and others simulating service provision across spatial and temporal scales. For the majority of biophysical models, stakeholder-oriented reasons for selection were rare.

Three types of ecosystem service models were applied widely (16 instances) in case studies. These models were chosen for a large number of reasons across all of the four categories identified. In the majority of cases, expertise, novelty, stakeholder participation and deliberation, and assessment of both current and future state of both ecosystem service demand and supply were key considerations. All were predominately used to raise awareness of the importance of ecosystem services and were applied to a range of provisioning, regulating and cultural services. Matrix approaches were chosen because of methodological reasons including available expertise within the case study team (simple matrix) or within the OpenNESS project (advanced matrix). Decision-oriented reasons were also important for the selection of these methods, in particular, the assessment of the current supply potential of multiple ecosystem services (provisioning, regulating and cultural) as spatially-explicit maps which are easy to communicate to stakeholders to raise awareness.

Deliberative and participatory methods (mapping, scenarios and valuation), 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, resolve conflicts or evaluate projects or policies. The methods which produced monetary outputs (benefit-cost analysis, cost-based methods, revealed and stated preferences, time use studies and value transfer), as well as being chosen for that purpose, also had a strong degree of stakeholder-oriented reasons, particularly stakeholder participation and ease of communication of the method and its results. Methodological-reasons related to existing expertise within the case study team and data, time and resource constraints were also cited as important. Monetary methods were generally applied to raise awareness and focused more on ecosystem service demand than supply, particularly for cultural services such as recreation.

Similar to the ecosystem service models, 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) decision-oriented 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, raise awareness, or develop criteria for screening or ranking alternatives. See Chapter 4 and Barton et al. (in press) for an analysis of patterns of method application to different decision contexts.

Figure 1.4 — Reasons for ecosystem service (ES) assessment method selection.

Column categories (left to right):
Expertise (team); Expertise (OpenNESS); Data constraints; Time constraints; Budget constraints; Novelty; Comparable; Established; New method; Uncertainty; Holistic; Stakeholder participation; Local knowledge; Stakeholder choice; Deliberation; Communication (method); Communication (results); Spatially-explicit; Fine scale (spatial planning); Broadscale (strategic overview); Across spatial scales; Across temporal scales; Current state; Future state (scenarios); Multiple ES; Trade-offs; Raising awareness; Project/policy evaluation; Conflict resolution; Screening alternatives; Ranking alternatives; Standard & policy target setting; Licencing / permitting / certification; Pricing, setting incentive levels; Damage compensation; Monetary output; Non-monetary output; ES supply; ES demand; Provisioning ES; Regulating ES; Cultural ES (quantifiable); Cultural ES (intangible); Supporting ES

Method	No
Biophysical model (SDMs)	2
Biophysical model (SITE)	1
Biophysical model (STM)	1
Ecological model	1
Hydrological model	1
ES model (ESTIMAP)	8
ES model (QuickScan)	6
ES cascade model	2
Simple matrix	2
Adv matrix (GreenFrame)	2
Deliberative mapping	1
Delib mapping (PPGIS)	4
Delib mapping (BGApp)	3
Delib map (MapNat App)	1
Participatory scenarios	2
Narrative analysis	5
Deliberative valuation	2
Preference assessment	5
Photo-elicitation	2
Photo-series analysis	7
Benefit-cost analysis	1
Cost-based	5
Revealed preferences	1
Stated preferences	2
Time use studies	3
Value transfer	2
BBNs	2
MCDA	4

Figure 1.4: Reasons for ecosystem service (ES) assessment method selection summarised by individual methods (bold horizontal lines separate different method types). 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 1.3.

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 1.2 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, so form a different source of information to the practical reasons 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 1.2a) and monetary valuation (Table 1.2c) 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 more straightforward to apply without specific expertise or needs for substantial data or resources, such as matrix-based mapping approaches, deliberative mapping approaches, value transfer approaches or photo-series analysis. Integrative methods, such as BBNs and MCDA, 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 modelling approaches and participatory scenario development, the latter being specifically designed to address this purpose. Some methods focus on specific ecosystem services, such as biophysical models of soil erosion, or specific groups of services, such as photo-series analysis of cultural ecosystem services. 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) or the demand for services by different stakeholders (e.g. PGIS, preference assessment methods, photo-elicitation or MCDA). The purpose for a monetary valuation study is particularly important in method selection as shown in Table 1.2c. 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.

Table 1.2: *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

Criteria	Preference assessment	Photo-elicitation	Photo-series analysis	Narrative analysis	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; MCDA = multi-criteria decision 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	MCDA
Reason for valuation:								
Explorative – method development	X	*	X	X	X	X		X
Informative - Awareness raising	*	X	*	*	X	*	*	X
Informative - Asset accounting	*	X		*	X			
Decisive - Priority-setting	*	X	X	*	*	X	X	X
Technical - Incentive design, pricing	*		X	~	*		*	
Technical - Litigation/Fines	~		~	~	*		*	
Addresses multiple ecosystem services	*	*	*	*			X	X
Enables trade-offs to be explored	*	*	X	X		X	X	X
Stakeholder participation			*	~		*	*	X
Incorporates local knowledge			X			*	*	X
Easy to communicate	X	*	X	*	X	X	*	X
Transparent (process easy to understand)	X	*	*	*	*	*	*	X
Integrated treatment of issues			X	*	*	*	X	X
Integration across disciplines			X	*		*	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	X
Addresses uncertainty:	X	*	X	X	*	*	*	*
High level of expertise needed	X	*	X	X		*	X	X
Large amount of resources needed	X		X	X		~	X	X

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, advanced matrix approaches and MCDA. 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 and the simpler ecosystem service mapping approaches.

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. Photo-series analysis is also spatially-explicit as the spatial coordinates of each photo are used as part of the assessment. 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. 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. 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.

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. 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. 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.

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, are designed to deliberately explore issues of uncertainty using conditional probability tables, whilst other methods such as the modelling approaches or time use studies 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. 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 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 1.2). 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 1.5.

The biophysical decision tree (Figure 1.5a) 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, 2016).

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.

The socio-cultural decision tree (Figure 1.5b) 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.

Figure 1.5: Decision trees for (a) biophysical, (b) socio-cultural, and (c) monetary methods.

(a) *Biophysical methods decision tree***:**

What is your purpose for the biophysical assessment of ecosystem services?

Understanding current and/or future dynamics underpinning ecosystem services

Mapping the current state of ecosystem services

What aspects of system dynamics are you interested in modelling?

What do you want to map?

A single or limited number of ecosystem services

Holistic assessment across many ecosystem services

What information do you want to represent in your map?

Is a simple approach sufficient for your needs?

Data from which the service can be modelled

Ecosystem processes and functions

Ecosystem Services

Complex interactions of nature and society

Service supply/demand based on biophysical/ socio-economic data

See Socio-Cultural Decision Tree for other deliberative approaches than those given here

If stakeholder input is important, participatory processes can be used with these approaches

BAYESIAN BELIEF NETWORKS

[BBNs can also be useful for socio-cultural and monetary valuation; see other decision trees]

If you are interested in inferring relationships from existing data rather than modelling processes explicitly

How does the data relate to the service?

Stakeholder perceptions of service supply/demand

Yes

No

BIOPHYSICAL MODELLING (e.g. Ecological & Hydrological models)

ECOSYSTEM SERVICES MODELLING (e.g. InVEST, ESTIMAP & QUICKScan)

What interactions do you want to represent?

Data can be mapped directly

Explicitly represent interactions and learning in society

Explicitly represent interactions between multiple sectors

Most modelling outputs can be integrated in Bayesian networks

Biophysical modelling can be the first step for ecosystem services modelling

AGENT-BASED MODELLING (ABMs) (e.g. CRAFTY)

SIMPLE GIS MAPPING

DELIBERATIVE OR PARTICIPATORY MAPPING (e.g. PPGIS)

[See Socio-Cultural decision tree]

SIMPLE MATRIX APPROACH (e.g. based on land use data only)

ADVANCED MATRIX APPROACH BASED ON MULTIPLE DATASETS (e.g. GreenFrame)

INTEGRATED ASSESSMENT MODELLING (IAMs) (e.g. CLIMSAVE IAP & IMAGE-GLOBIO)

These model outputs can be the used as an input or pressure in ecosystem services modelling

GIS maps can be used as part of deliberative or matrix mapping approaches

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

What is your purpose for the socio-cultural assessment of ecosystem services?

Facilitate stakeholder interaction and dialogue

Collect data on people's preferences, values and worldviews

Are you interested in current trade-offs or alternative futures?

Are you interested in human perceptions on ecosystem services, or numeric information about preferences and values people hold?

Trade-offs

Preferences and values

Are you interested in quantitative or qualitative results?

Do you need monetary information?

Quantitative

Semi-quantitative

No

Yes

Do you need monetary information?

What type of results are you interested in?

See Monetary Methods Decision Tree

No

Futures

Human perceptions

Semi-quantitative

Fully quantitative

Do you need spatially-explicit results

Do you need spatially-explicit results?

Are you interested in stated preferences or actual behaviour?

No

Yes

Are there major data uncertainties?

How much time do you have for stakeholder meetings?

Qualitative

No

Yes

Stated preferences

Actual behaviour

Several days

How strongly do you rely on visual information?

Yes

No

Yes

One day

Are there major data uncertainties?

Visual aid not necessary

Photos as proxies for ecosystem services

Landscape pictures to capture preferences

No

Yes

No

Yes

DELIBERATIVE MONETARY VALUATION

MCDA

BBN

ES MODELLING (e.g. QUICKScan)

MCDA (SPATIAL)

BBN (SPATIAL)

DELIBERATIVE VALUATION (e.g. photo-voice, valuation workshop, citizen's jury)

PARTICIPATORY SCENARIO DEVELOPMENT

NARRATIVE ANALYSIS

PREFERENCE ASSESSMENT (Ranking or Rating)

ES CARD GAME

PHOTO ELICITATION SURVEY

PPGIS

TIME USE STUDIES

PHOTO-SERIES ANALYSIS

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[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 1.3a) or monetary (e.g. deliberative monetary valuation; Table 1.3c) techniques.

(c) Monetary methods decision tree:

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 1.5c) provides a graphical overview of basic differences in the purposes of various valuation method groups. The first question in the tree asks about the purpose of monetary valuation. 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. These high level purposes were defined based on Gómez-Baggethun and Barton (2013) and Laurans et al. (2013). 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 (Boardman et al. 2006; Belton and Stewart 2002). 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 all monetary values are not necessarily commensurable and 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 go and 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).

 Whether BCA or MCDA is chosen for decision-support, some form of biophysical assessment of the impacts of decision alternatives is needed for all of the monetary valuation methods.   This is not

illustrated in the monetary decision-tree, but the assumption is that an biophysical impact assessment has been carried out prior to conducting monetary valuation.

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 calculation 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).

4. Discussion

4.1 Method selection considerations

This chapter has aimed at providing comprehensive guidance to researchers and practitioners for selecting different biophysical, socio-cultural and monetary techniques for ecosystem service assessments. Thirty three methods 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. 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., in press). Operational methods address a clearly defined study purpose within constraints on budget, time, data and expertise (Chapter 4 and Barton et al., in press). Furthermore, appropriate methods address a range of ecosystem services which are relevant for the study purpose (Chapter 3 and Jacobs et al., in press).

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, 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 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., in press). 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 chapter examines reasons for selecting individual methods. However, many case studies selected more than one method and combined methods in different ways. Chapter 2 and Dunford et al. (in press) explore 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 (Chapter 3 and Jacobs et al., in press).

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 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 Chapter 3 and Jacobs et al. in press). 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. Broad contexts for valuation include explorative, informative, decisive and technical design purposes (see Table 1.3c) and Chapter

4 (and Barton et al., in press). 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 can 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.

6. Epilogue

Chapter 1 was peer reviewed for publication in Ecosystem Services and a number of additional edits were made in response to the reviewer's comments. Reviewers were particularly interested in more information on the case studies and so the finished manuscript includes additional supplementary material about case study locations. We also considered in more detail the transferability of the

approach, reflecting on the fact that, though based on a limited number (27) of predominantly European, developed world, cases, much of the iterative, expert-based approach was designed to be generic enough to apply to other regions and cases outside of the OPENNESS project. We also further expanded the methodology section to explain how the method groups were developed and the decision trees created and particularly to highlight the role played by method experts (people who had experience working with the individual methods across the case studies) in the process. We highlighted the role of these method experts in, for example, the development of the tables of method selection criteria (Table 1.2 a-c) and in the sense testing of the final decision trees (Figure 1.5a-c). We also included references to additional literature outside of the OPENNESS case studies that were used to help structure the approach taken within the paper and updated a number of the figures and diagrams to simplify the messages in line with reviewer requests. The discussion was expanded slightly to provide explicit critique of the limitations of the empirical data on which the decision trees were based and additional clarity over the purpose of the trees was added: it was explained that they are not designed to be prescriptive but to provide assistance in screening methods in order to accomplish more integrated assessment and valuation of ecosystem services.

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Chapter 2 - Integrating methods for ecosystem service assessment: experiences from real world situations

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Chapter overview

This chapter draws on an analysis of OpenNESS experiences in 26 of its case studies, to detail both the diversity of ways that biophysical, socio-cultural and monetary approaches were combined in practice, and the reasons driving selection in different contexts. The chapter attempts to synthesise these experiences to provide take-home messages that illustrate where, and in what contexts, different methodological combinations were used. The actual combination of approaches discussed here provides a useful contrast to the combinations prescribed by generic considerations in the methods decision-tree approach explained in Chapter 1. The chapter provides suggestions for those working in ecosystem service assessment drawn from experience of the case studies. The findings of the OpenNESS case studies stress that methodological plurality, flexibility and creativity are key if the ES concept is to best address the practical challenges posed by real world situations.

Chapter Keywords

Ecosystem service methodologies; Case studies; Combination of methods.

Published article

1. Introduction

The popularisation of the Ecosystem Services (ES) concept has led to a significant uptake of ecosystem service based approaches in national and international policy frameworks (TEEB, 2010; Bateman et al., 2014; UN et al., 2014; IPBES, 2015, Maes et al., 2016). This, along with increased awareness of the interconnectedness of the natural environment and the widespread contributions of the natural world to human wellbeing, has put increasing pressure on practitioners in the land use and environment sectors to assess and manage natural capital in a way that better reflects these holistic benefits.

This poses significant challenges. As the Ecosystem Service concept has become more widely recognised, so the number of tools/methods (treated here as synonyms) available to assess ES has increased (Chapter 2; Harrison et al., in press; Bagstad et al., 2013). Individual ecosystem service tools, however, are often insufficient to meet the varied and different needs of land management challenges, and practitioners will therefore need to find the right combinations of tools to meet their ends – and to enable them to assess the broad range of values provided by nature (Chapter 3; Jacobs et al., in press). Whilst there are a number of studies that attempt to provide guidance as to which tools to use under which circumstances (e.g. Vatn, 2009; Bagstad et al., 2013; Martinez-Harms et al., 2015; Ruckelshaus et al., 2015; Grêt-Regamey et al., 2017), there has to date been no study that looks at the range of tools required to address real-world case studies or takes a bottom-up, example-based look at the factors that drive method selection within practical example cases.

In the OpenNESS project, a range of ecosystem management/planning challenges were selected by practitioners in 26 real-world case studies (see SM1 at the end of this chapter for a full list and descriptions). The case studies provided a test bed for assessing the utility of ecosystem service tools in practice. In this chapter we draw on detailed analysis of ES tool use in the OpenNESS cases to identify both i) in what ways tools are combined to meet different needs in different situations and ii) the factors that drive tool selection from the point of view of the experts driving the research within the case studies.

2. Methodological approach

The OpenNESS project (EU FP7; 2012-2017, www.openness-project.eu) investigates the factors that influence the extent to which the Ecosystem Service concept can be put into practice in a number of practical, real-world case studies. The case studies are predominantly in Europe (22 cases), but also include cases in India, Kenya, Argentina and Brazil (see SM1). The cases are split across a range of biophysical contexts (e.g. forests, mountains, mixed rural areas, wetlands and rivers) and across a range of land management challenges and policy contexts (e.g. assessment of urban green infrastructure, national park management, forest planning or biodiversity offsetting; see Dick et al. this volume for details). In the case studies a *research team*, funded by the project, worked alongside a team of *stakeholders* who are involved with the management of and/or have some interest and/or dependency on the case studies' central issue. The work described below is based on the *research team's* explanation of the factors that influenced their selection of tools to meet the *stakeholders'* needs within the case study.

Data on tool use was collected as part of an iterative process within the OpenNESS project through a series of questionnaires and workshops with the 26 case study research teams (Figure 2.1a). Initial surveys encouraged the research team to express in their own words the reasons for the selection of individual tools. This data was interpreted and coded into themes that reflected the major factors taken into consideration when methods were selected. These factors, referred to as "*considerations*" within this chapter, covered a broad range of issues under six main themes:

1) the types of **ecosystem service** that were the focus of the case study;
2) the **management or policy context** of their study: e.g. were they interested in exploring ideas, providing information, making decisions or designing policy instruments; for more information see Barton et al., (in press; Chapter 5);
3) a range of **pragmatic constraints** that might have influenced their choice of methods: such as budget, time and expertise;
4) considerations related to the **research process,** such as whether the technique was novel or transferable;
5) particular **methodological considerations**, such as a method's ability to involve stakeholders, provide spatially explicit outputs or address uncertainty;
6) factors related to the **stakeholder-driven** nature of the OpenNESS research, such as whether the method selection was driven by the end-users themselves.

October 2013 (**WS1**) Initial discussions with case studies about which methods they might use.	
November 2014 (**WS2**) Training workshop at which methods were showcased and practical support with them was offered	
Jan 2015 Q1: Initial questionnaire to identify which methods are being used, for what purposes and why the methods had been selected.	
April 2015 (**WS3**) Method combination workshop to explore the ways that different methods were used in combination. Experiences across case studies were shared.	
October 2015 (**WS4**) Methodology mind-mapping workshop: mind maps were used to describe the process of method selection within the cases	
September 2016 Q2: Method use questionnaire to identify and assess the considerations that had led to method selection to date within the cases.	
a)	b)

Figure 2.1 a) Overview of workshops (WS1-4) and questionnaires (Q1&2) focussed on method combinations and b) example mind map from WS4 methodology mind-mapping workshop.

The full list of method considerations within this chapter is shown in Table SM2.2. A further survey was circulated after the completion of the OpenNESS case study research assessed within this chapter in which the case study research teams were asked to identify all the tools used within their case study. In addition they were asked, for each method, to provide a score from 0-2 that reflected the

extent to which each of the considerations shown in Table SM2.2 influenced their decision to use that tool within their case study (0 = not at all; 1 = to some extent; 2 = definitely).

In addition to survey data, a number of workshops were used to a) expose the case study researchers to the variety of methods available for ES assessment (WS1 &2); b) to ascertain from the case studies how they were using methods to meet their specific goals (WS1-4) and c) to understand how methods were being combined (WS 3-4). The final outputs of the workshop process were participatory mind maps (e.g. Figure 2.1b). Each mind map details both the methods used, the ways in which methods are combined and considerations that influenced the method selection/combination process.

The results in this chapter draw on the questionnaire (Q2) and final mind map datasets (from WS4). As the focus is on method combinations, only the results for the 23 case studies that reported more than one method in the Q2 questionnaires are presented (see SM1 and Figure 2.2). The questionnaires and mind-maps were thematically analysed across all case studies to identify common factors influencing method choices within the individual case studies and the reasons driving which methods were combined. Where additional information was needed, ad hoc interviews were performed with the case study research teams to fill in extra details missing from the mind maps and clarify uncertainties.

For discussion, methods are grouped into seven overarching method classes outlined below, the classes are broadly based around the biophysical, socio-cultural and monetary approaches conventionally discussed (Gomez-Baggethun et al., 2015) but with subdivisions for mapping and modelling approaches, hybrid groups that combine elements from these core groups (e.g. expert-based mapping, Participatory GIS) and integrative approaches that attempt to synthesise other methods' outputs (Table SM2.2 details the individual methods within these groups):

1) *Biophysical models*: often complex models focussed on detailed quantitative understanding of biophysical relationships within the environment (examples include hydrological, ecological or climate envelope modelling). These approaches are not forcibly spatial, but can be. Often biophysical models pre-date the ES concept, they may need to be modified to directly address ecosystem services.

2) *Integrated mapping-modelling approaches*: these approaches combine spatial approaches with an element of bio-physical modelling to extrapolate from spatial datasets to ecosystem services. These methods are often designed specifically to address ecosystem services and include established methods such as InVEST and ESTIMAP (Zulian et al., 2014).

3) *Expert-based mapping approaches*: this class of methods include approaches based primarily on mapped data that produce ES outputs by applying some kind of expert-scoring. This includes the simple Burkhard et al. (2013) matrix approach and more advanced versions such as GreenFRAME (Kopperoinen et al., 2014) which use additional datasets to improve the outputs.

4) *Participatory mapping approaches*: this class of methods focus on using mapping as a stakeholder process as a way to capture both spatial and socio-cultural data directly from stakeholders: it includes all forms of participatory GIS including methods based on citizen science data entry.

5) *Non-monetary valuation*: this covers a wide range of methods including non-monetary alternatives to common monetary approaches (e.g. time use, preference assessment); deliberative and narrative approaches (such as interviews and focus groups) and methods to assess cultural ecosystem services through the interpretation of photography (photo-elicitation and photoseries analysis). This group is also referred to as *socio-cultural methods* in other chapters in this report.

6) *Monetary valuation*: approaches that calculate a monetary value for ecosystem services through a range of means (such as value transfer, hedonic pricing or stated preference).

7) *Integrative approaches*: these methods are designed to synthesise data from different sources and include methods such as Bayesian Belief Networks (BBNs), Multi criteria decision analysis and scenario development approaches.

3. Results

3.1 Which methods are used in combination?

Across the 23 case studies which combined multiple methods (see Figure 2.2), a wide range of individual methods were combined (Figure SM2.2). The number of methods combined varied widely between case studies: the majority of studies (78%) combined at least 4 methods and 39% combined 6 or more: the most methods combined in one case study was 14 (Oslo): Figure 2.2). Figure 2.2 shows the variety of method combinations that are used to address the different needs of the case studies. Whilst it is clear that non-monetary, participatory mapping and integrative approaches are used in over half the cases (86%, 76% and 57% of them respectively), there is no set pattern applied in all cases, there are no cases that use all types of methods and there are examples of case studies which do not use each type of method.

Method	Proportion (%)
Biophysical modelling	35
Integrated mapping-modelling approaches	42
Expert-based mapping approaches	23
Participatory mapping approaches	65
Non-monetary valuation	81
Monetary valuation	27
Integrative approaches	50

Number of methods used in case study (by case): Oslo (OSLO) 14; Donana (DONN) 10; Romania (DANU) 9; Hungary (KISK) 8; Sierra Nevada (SNNP) 8; Slovakia (TRNA) 6; Carpathians (CAPM) 6; Cairngorms (CNPM) 6; Portugal (SACV) 6; Barcelona (BARC) 5; Patagonia (SPAT) 5; Kenya (KEGA) 4; Germany (BIOG) 4; Warwickshire (WCSO) 4; Belgium (CRKL) 4; Italy (GOMG) 4; Loch Leven (LLEV) 4; Essex (ESSX) 3; France (ALPS) 3; Brazil (BIOB) 2; Belgium (STEV) 2; Helsinki (SJBB) 2; India (BKSU) 1; Vitoria-Gasteiz (VGAS) 1; Finland (BIOF) 1; Waddensee (WADD) 1.

**Figure 2.2**: *Overview of method usage within the 26 case studies; white circles indicate a single method; black circles indicate more than one method of the same type. Line colours reflect overarching method classes: biophysical (greens); soico-cultural (blues); monetary (pink) and integrative (grey). The 3 cases which recorded using more only one method have grey headers and are not included in the calculation of the proportion.*

a) *Network of pairwise linkages: thickness of line is relative to number of case studies with an example of both method types. Grey shades also reflect proportion of the 23 cases with that linkage: lightest grey (≥33% of case studies); mid grey (≥20% of case studies; black all other cases.)*
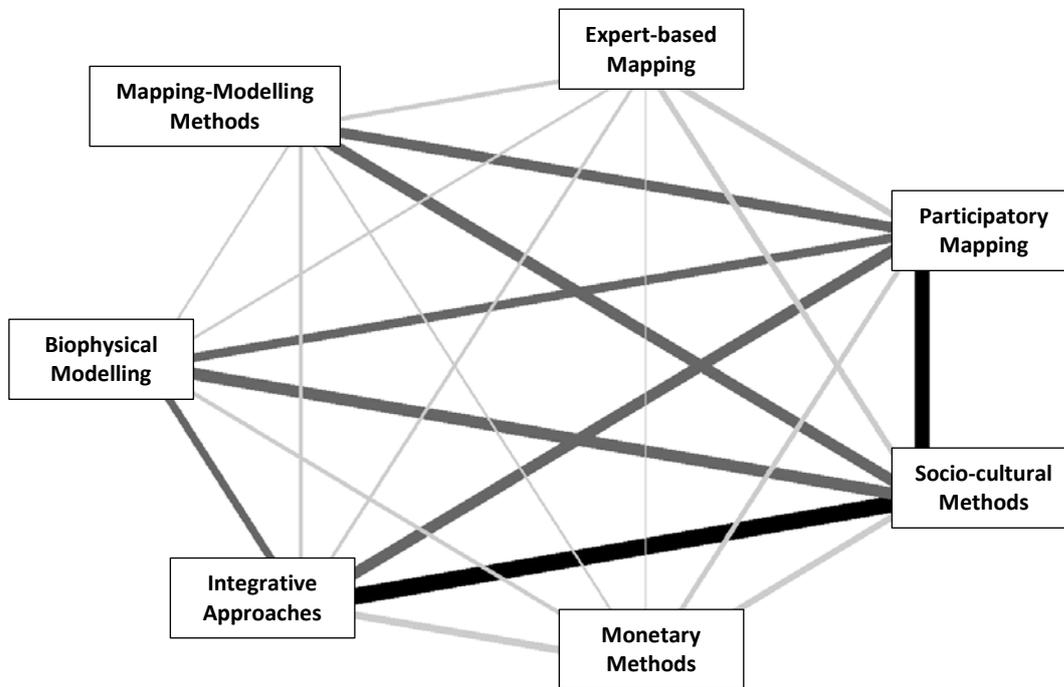
b) *Pairwise linkages between methods: numbers in the top column are the total numbers of cases using that method. In rows proportions are shown for each method of the methods that also use another method type in the same case; diagonal rows are cases using more than one example of the same method within an individual case; shades indicate proportion by quartile (grey <=25%; light green <=50% mid green <=75% green <=100%).*

Biophysical modelling	Integrated mapping-modelling approaches	Expert-based mapping approaches	Participatory mapping approaches	Non-monetary valuation	Monetary valuation	Integrative approaches	
9	11	6	16	21	6	12	Case studies using this method
Proportion of case studies using method above that also use …							
0%	18%	33%	38%	38%	50%	50%	… Biophysical modelling
22%	27%	50%	44%	38%	33%	33%	… Integrated mapping-modelling approaches
22%	27%	17%	31%	24%	17%	25%	… Expert-based mapping approaches
67%	64%	83%	13%	67%	67%	67%	… Participatory mapping approaches
89%	73%	83%	88%	57%	83%	92%	… Non-monetary valuation
33%	18%	17%	25%	24%	33%	42%	… Monetary valuation
67%	36%	50%	50%	52%	83%	33%	… Integrative approaches

Figure 2.3a & b *pairwise method combinations across the 23 case studies.*

The most common linkages between methods within the 23 case studies are between socio-cultural and participatory methods, with socio-cultural and integrative approaches the second most common (Figure 2.3a). Figure 2.3b shows that for the method types taken up in smaller numbers some are more often combined with particular methods than others.

Less than 25% of cases using biophysical methods combined these with mapping or mapping-modelling approaches, whereas over 60% were combined with integrative approaches, participatory mapping and non-monetary valuation. This may reflect the fact that when detailed modelling is provided, there is less demand for map-based approaches. However, within the map-based approaches 50% of studies using expert-based approaches also use integrated mapping-modelling. The distribution of the methods used in the monetary valuation case studies shows that these methods were very frequently combined with non-monetary and integrative methods within the OpenNESS cases (83%), and that they were commonly combined with biophysical modelling (50%) and participatory mapping approaches (67%). For non-monetary, monetary valuation and integrated approaches a noteworthy proportion of case studies (57%, 33% and 33% respectively) used more than one method from the same method group, e.g. Oslo used 8 monetary methods and Hungary (KISK) and Sierra Nevada (SNNP) used a suite of 4 and 6 non-monetary approaches, respectively.

The overview analysis presented is sensitive to a number of factors that influence the methods selected within the OpenNESS cases, including a number of biases with respect to the expertise within the consortium and the research interests of the project research teams (see section 3.3.4). However, two take-home messages are clear: 1) even at the aggregate level there is no one combination of methods that addresses the needs of all the case studies and 2) that even within broad method groups there are considerations that mean that a single method from that group may not be enough to meet a given case study's needs. However, without a more detailed understanding of the reasons behind the selection of methods, addressed in the following section, further interpretation of raw statistics is of limited value.

3.2 In what ways are methods linked?

Through discussion with the case study representatives and by analysis of the mind maps it became clear that methods were linked in many complex and different ways which varied between the case studies. These included: i) input-output transfers of data between methods but also ii) transfer of ideas, concepts and learning; iii) combination of methods into hybrid methods iv) evolution of methods to customise them better to the context; v) cross-comparison of method outputs for cross-checking/validation; vi) transfers of method experience across contexts and vii) through individuals.

These different ways of combining methods are discussed in detail in the sections below with particular reference to two example case studies, Oslo city, Norway and the Cairngorms National Park in Scotland (CNPM), but similar findings were identified across the case studies. In Oslo, there were three aims of the case study: O1) to assess at the city-scale the monetary value of ES from Green Infrastructure; O2) to showcase local case study examples of the monetary value of ES to assist decision-making; and O3) to demonstrate the ability of ES mapping tools.
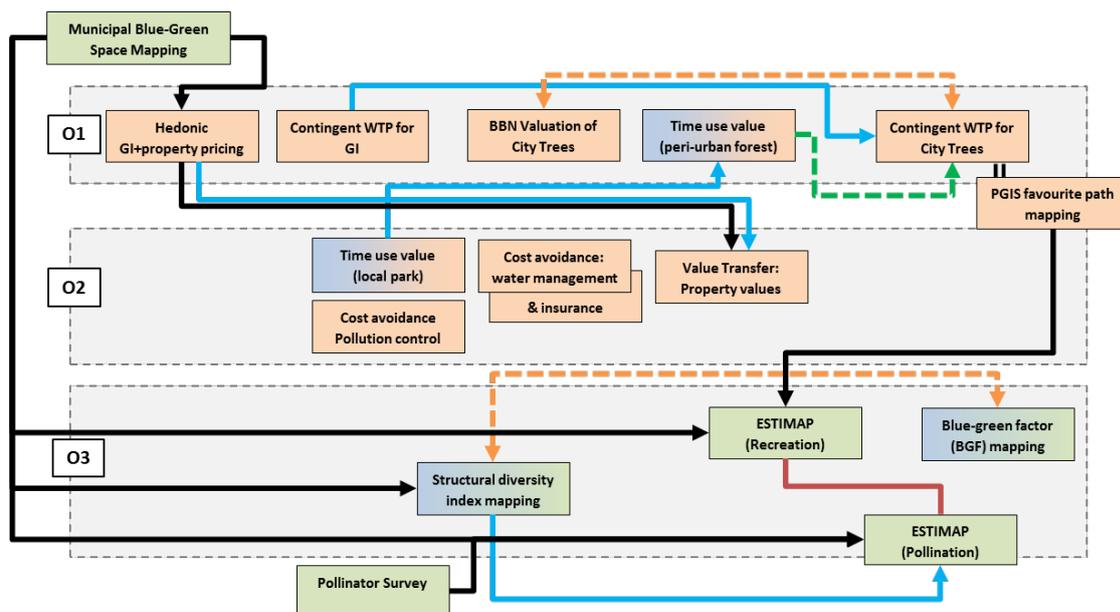
a) Oslo case study. Sub projects: 1. City-wide monetary valuation; 2. Local site monetary valuation; 3. Exploring mapping methods.
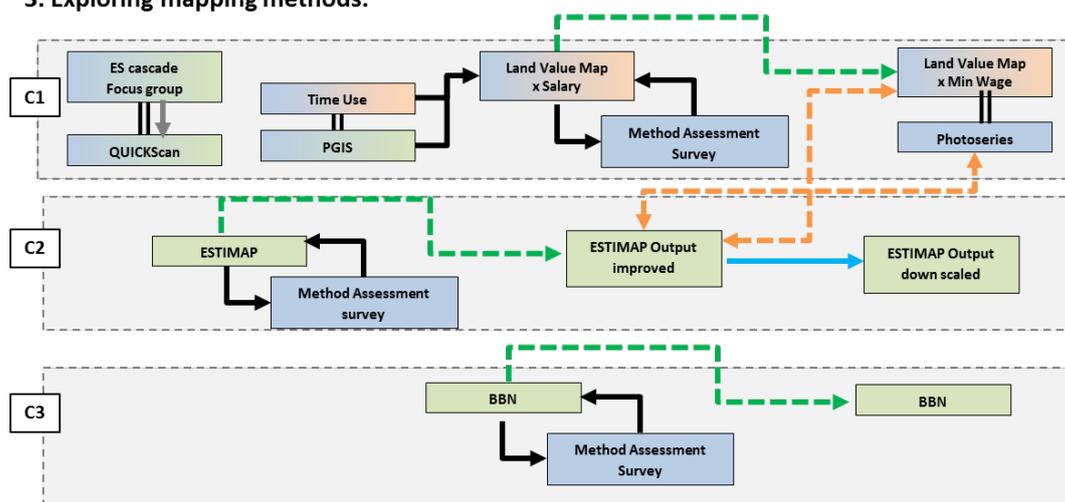
b) Cairngorms National Park case study. Sub projects: 1. Land Management at sub-park scale; 2. Land Management at Park scale; 3. Initially PES but refocused to risk assessment for a water company
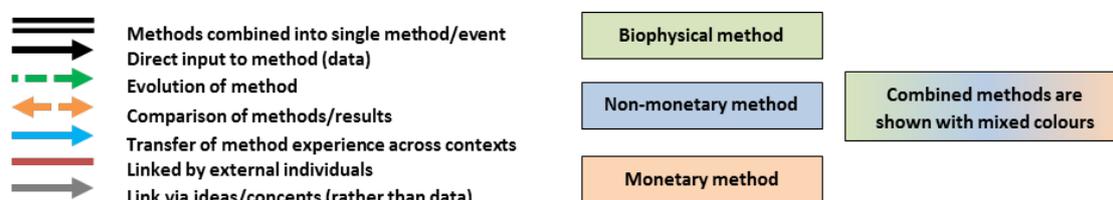
***Figure 2.4a and b)*** *Process diagrams of two example case studies Oslo, Norway and the Cairngorms National Park, Scotland.*

In the Cairngorms, the three aims were: C1) to assess the ecosystem service provision of a single land management unit (a subset of the Cairngorms National Park); C2) to assess the ecosystem service provision of the whole park; and C3) to assess in detail a water supply issue in a particular catchment

within the study area. Figure 2.4 provides a diagrammatic representation of how these methods were linked within the case studies.

The first thing to note is that tool selection in both case studies was driven by multiple goals related to different ES assessment issues, and this was the situation for many of the case studies. Secondly, even where a specific aim was identified (e.g. for a subproject O2), a number of different methods were combined to achieve it. Thirdly, within a project targeted with a specific aim the method types combined vary widely: O2, which aimed to demonstrate monetary approaches, focuses almost exclusively on these methods, whereas C1 uses methods that combine aspects of biophysical, monetary and non-monetary approaches (see Section 3.3 re the reasons for method selection).

3.2.1 Input-output transfers of data

Input-output transfers of data between methods are perhaps one of the first ways one might think about combining methods, i.e. data output from one method serve as the input to another. An example of this is in O1 where the PGIS work to identify people's favourite walking routes was used as an input layer for the mapping of recreational opportunities with the mapping-modelling method ESTIMAP.

However, the Oslo example also highlights that inputs may come from methods outside of the case study research, e.g. from existing datasets or prior research. In the Oslo case this includes the blue-green space mapping performed at the municipal level by the Agency of Urban Environment, which forms an input to methods in both O1 and O3 as shown on Figure 2.4. This demonstrates that input-output method linkages may extend well beyond the case in hand to other projects in the same area (e.g. the Municipal Plan) and beyond (e.g. value transfer from other studies). It is important, therefore, to remember that primary data collection methodologies (e.g. any biophysical measuring techniques) and any manipulations applied to this data (e.g. summaries, statistics) are also part of the method selection chain. This is an important point when considering the types of value reflected by a given method combination (see Chapter 3; Jacobs et al., in press). Furthermore, this incorporation of existing knowledge/data can be crucial and has also been shown to increase the acceptance of the ES approach by local stakeholders (e.g. Barcelona; BRCN).

Although common to many of the case studies, input-output data linkages were not always highlighted by the research experts during the assessment. Some case studies, instead, described an approach that used a suite of different methods used to highlight different aspects of ES within the study context (e.g. the showcasing of monetary methods in O2, Essex (ESSX), Warwickshire (WCSO). This may reflect the fact that many of the studies have not used an integrative method to pull together the output from the methods. However, many of the case-studies will have used reports (e.g. Reinvang et al., 2014; Barton et al., 2015) or presentations, meetings or workshops with end users (e.g. Kenya (KEGA), Portugal (SACV)) to perform this task without recording that these processes are integrative methods in themselves. It is important to remember that the method chains may well be long and extend beyond the issue in question, and possibly the geographical and temporal bounds of the case study. Depending on the study purpose this may have implications for how the results can be used and will influence the views and environmental values explicitly recognised within the process.

3.2.2 Direct links (concepts, ideas and learning)

Combining methods within a case study is part of an ongoing iterative process and in some cases it is not necessarily data that is transferred between methods, but broader learning of concepts or ideas. In the Kakamega Forest, Kenya case study (KEGA), stakeholder workshops preceded all other methods to bring all participants to a similar level of understanding by translating (from English to vernacular), learning and sharing knowledge of ES concepts, and especially using the Cascade model (cf. Carmen et al., in press). Similarly, in the Cairngorms study (C1) a workshop run on the Ecosystem Service Cascade model (Dick et al., 2016) was run prior to the implementation of a participatory mapping exercise to expose stakeholders to the concepts of ecosystem services so that they could better transfer those ideas/ ES thinking into the PGIS workshop. This is a specific example in C1 is illustrated on Figure 2.4, but learning and development of concepts and ideas though the application of methods underpins all the linkages between methods in all cases.

There are many methods, particularly deliberative approaches, that are specifically designed to maximise this learning through developing shared understandings between individuals. Doing so can often work as an enabler for other research, as was discovered in the Belgian case study (CRKL). In this case, the initial exposure of stakeholders to the ES concept through broad-scale ES mapping had led to a "bottleneck" and "low expectations of usefulness" as stakeholders perceived the method to be inapplicable at the local level of their interest. This was overcome by applying a stakeholder demand analysis including the ES card game. The approach "confirmed the relevance" of the ecosystem services to the stakeholders and enabled future research.

3.2.3 Method hybridisation

In addition to using methods in series, in many case studies key aspects of different methods were combined to produce hybrid methods. In Oslo, participatory GIS and monetary valuation were combined in a web-survey using participant mapping of favourite walking paths followed by a willingness-to-pay assessment of the value of city trees. Similarly in the Cairngorms (CNPM) example a monetary/non-monetary method (time use) was hybridised with PGIS approaches to produce maps of land value in terms of both time spent and monetary costs. In Patagonia (SPAT) a biophysical model was co-produced with local experts by developing a State and Transition Model (STM) within a deliberative workshop: this allowed experts to co-design the STM used to evaluate forest change with the research team. In these instances, combining methodologies helps to overcome weaknesses in the individual approaches, e.g. maximising inclusion of local ecological knowledge/specialist expertise whilst producing spatial outputs/biophysical models. In another example, the French Alps (ALPS) developed a spatial BBN to combine the trade-off exploration opportunities possible with BBNs with GIS tools that allowed forest managers evaluate the spatial implications and trade-offs between forest production and conservation measures to preserve biodiversity in forested habitats (Gonzalez-Redin et al . 2016).

Whilst there is a clear overlap between hybrid and combined methods, the aim here is to highlight that methods can be combined creatively in ways that maximise the advantages and minimise disadvantages of both, and that doing so can better customise methods to each case study.

3.2.4 Method evolution and development

In many of the case studies it was clear that the method combinations resulted from the evolution of individual methods into new methods. In some instances this was a natural progression. For example, in Slovakia (TRNA), simple matrix-based mapping methods were developed to provide broad information on the current ecosystem services within the territory based on land use. Then, by including stakeholder data from questionnaires and additional environmental datasets, the method was further developed as an advanced matrix approach more akin to Greenframe (Kopperoinen et al., 2014). This was considered more scientifically sound and suitable for the case study's planning purposes. The Romanian case (DANU) followed a similar approach, using matrix approaches initially, before moving on to participatory mapping/modelling (QUICKscan) and integrative approaches (MCDA).

In other examples, methods evolved in an iterative manner as a response to feedback, learning or changes in circumstance within a case study. In the Cairngorms C1 example, the time use + PGIS hybrid method evolved in response to method assessment surveys that expressed stakeholder concerns that the method was based on the salary multiplied by time spent of the participants who completed the questionnaire. The feedback suggested that multiplying by the minimum wage would be a fairer reflection and the method was updated in response. In OSLO, an initial scoping study that focused on the value of green space using secondary data evolved into contingent valuation using primary data as a result of a change in study focus from green infrastructure (in general) to city trees. Similarly, learning between case studies led to the evolution of methods across case studies: PGIS approaches trialled in Warwickshire (WCSO) were modified when the method was transferred to Essex (ESSX) based on case study learning that suggested that, in this context, the approach used provided better responses when focussed on cultural ecosystem services (rather than provisioning/ regulating).

In other cases innovative methods were developed to address aspects particularly important to the cases. For example, in Hungary (KISK) it was seen to be very important to include the values of future generations in ecosystem service assessments and a new "drawing competition" methodology was developed, expanding on ideas found in other non-monetary methods but specifically targeted to ensure "young people get to have a voice". In the method young children were asked to contribute pictures related to their perceptions of the value of nature and their views of the future. These were included along with spatial modelling, statistical approaches and participatory mapping outputs in a final workshop that led to policy recommendations.

Finally, in some cases new methods had to be developed because existing methods were not available or context appropriate. In Patagonia (SPAT), where there was limited available data on cultural services and many of methods proposed within OpenNESS were customised for Europe the case developed their own methods, many of them based on the other proposed methodology. As a result, they led the development of the photo-series approach to map and quantify cultural services.

The point with regard to method evolution and development is that to meet a case study's needs, approaches need to evolve with time and respond to feedback / new opportunities that arise within the study; and that creativity and flexibility increase what it is possible to achieve when combining approaches.

3.2.5 Method comparison

Most of the case studies in OpenNESS were place-based, and there is both a spatial and a temporal aspect related to the domain of the study. Thus, it was very common for case studies to address the same issue (e.g. a particular ecosystem service) with multiple methods as part of a process of cross-checking and validation. Often these methods addressed different aspects of the same issue. In the Cairngorms example, photoseries analysis (developed in C1) provided information on revealed preferences for cultural ecosystem services, based on where there is evidence for photos of nature being taken. ESTIMAP (from C2) also produces cultural ecosystem services information by identifying recreational opportunities based on the location of natural areas relative to population centres. By applying the two methods within a single case study, a more rounded understanding of a particular issue can be developed.

3.2.6 Method transfer

Methods were also linked within the case studies by the direct transfer of methods between different issues and locations. In the Oslo example, the time use methodology initially developed at the local scale is later applied at the municipal level (O2→O1) whilst the inverse is true for the hedonic pricing method (O1→O2). In addition, contingent valuation is transferred from one topic to another at the same scale (i.e. from a focus on all green infrastructure to a focus just on city trees). Within the OpenNESS case studies the photoseries methodology for cultural ecosystem service assessment (Martínez Pastur et al., 2016; Tenerelli et al, 2016) was also a key example of method transfer. There was recognition of the challenges of assessing cultural ecosystem services, especially those such as aesthetic beauty due to their intangible and subjective nature, and the ability of photo series to rapidly assess these issues meant that it was used in 11 cases (see SM2).

There is often a synergy between method transfer and method evolution (section 3.2.4). The ESTIMAP methodology, for example, evolved considerably as a result of its application to different case studies. Initially intended to be applied in a standardised manner customised at a European scale (Paracchini etal., 2014), through testing across a number of OpenNESS case studies the methodology was adapted to be applicable at much finer resolutions with successful application in both national parks (e.g. Cairngorms (CNPM), Costa Vicentina, Portugal (SACV)) and urban areas (OSLO, Trnava, Slovakia (TRNA), Helsinki (SIBB), Barcelona (BARC)): this was not just a downscaling of the approach but an evolution of the method from one based on standardised datasets to one that could be customised to local needs.

3.2.7 Individuals

In addition to the links between methods highlighted above, the roles of individuals, particularly those with methodological expertise, were highlighted in a number of case studies. In the Oslo case study, the monetary valuation expertise of the lead researcher was a key aspect linking all the methods used, influencing both the selection of methods and how they were applied in practice. Similarly, many case study teams noted that the availability of methodological expertise encouraged engagement with particular methods (see 3.3.4). For example, close working relationships with the lead ESTIMAP expert in both Oslo and the Cairngorms cases was a factor that encouraged the development of the ESTIMAP methodologies in these studies (O3, C2) and the others using the method as listed in Section 3.2.6.

Case study stakeholders and end users are also key links between methods: if the same stakeholders remain engaged with the method development process this can help retain a lot of the learning highlighted in Section 3.2.2. Furthermore, in a number of cases stakeholders were the driving force behind method selection, identifying issues that require consideration and in some cases detailing the exact method or types of method to be used.

3.3 What factors drive method choices within case studies?

The OpenNESS case studies cover a broad range of real world contexts and an analysis of the considerations influencing tool use reveals a number of transferable messages. Figure 2.5 shows the number of case studies that identified a consideration to be a reason that they selected a particular method. Of the 17 considerations identified, all were seen to be relevant in at least 25% of the case studies and the majority (12) are relevant ≥60% of cases. The decision context and encouraging dialogue are both issues seen as relevant to 100% of case studies. In addition, over 80% of cases considered i) expertise; ii) considering supply and/or demand for ES; iii) the specific ecosystem services of the case studies; iv) need for a systemic approach and analysing trade-offs; v) research-related considerations (see SM2); vi) ease of communication and vii) spatial requirements as considerations for at least one method.
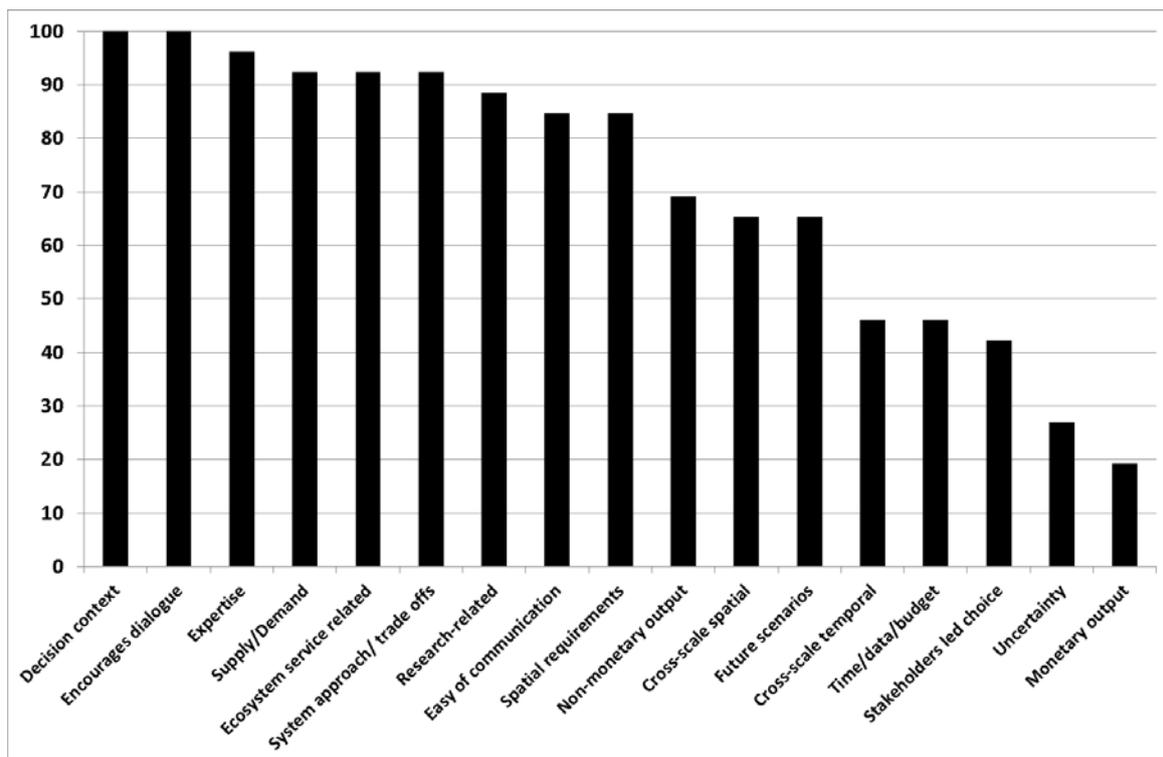
Figure 2.5: *Percentage of case studies regarding a consideration to be of "definite" relevance to their selection of at least one of the methods within that study.*

At a case study level, considerations interact in a far more complex manner (Figure 2.6). However there are some overall messages (Sections 3.3.1-3.1.5 below) that emerge from the interpretation of the considerations behind method selection, and in this section we provide examples from the two case studies introduced in Section 3.2

Figure 2.6: *Detailed analysis of method selection considerations within the Oslo and Cairngorms (CNPM) case studies. Coloured bars indicate that the research team saw a consideration as of "definite importance" whilst light grey indicates a consideration was of "some relevance" to the selection of the method. Methods codes are: Hd= Hedonic pricing; WTP = Willingness-to-pay; BBN = Bayesian Belief Networks; TU = Time Use; CB* = Cost-based; FG = Focus group; Qs = Quickscan; LVM = Land value mapping; E-R/E-P = ESTIMAP (recreation / pollination).*

3.3.1 Ecosystem services and decision contexts are important – but not always the primary consideration

As indicated in the previous section, the case study decision context is a primary consideration: in large numbers of case studies both the ecosystem services within the case and the purpose of the study are highlighted as considerations. However, within a case study there is considerable variation within both, i.e. a single project may use tools to address different ESs or to address different aspects of the decision context. In the Cairngorms for example, the Cascade Focus Group (FG) and Quickscan (Qs) methods were used to introduce the wide range of ecosystem services and other methods were then used to focus on specific ES (e.g. photoseries analysis (PS) for cultural ES).

Similarly in Oslo different aspects of the decision context were addressed by the different methods – with Time Use and Willingness-to-pay being used for informative purposes and other methods being used across all decision context levels (O1). It is important to note that time / resource constraints (see 3.3.4) were part of the reason for the selection of both of these methods: the methods were relatively quick and easy to apply – making them ideal for informative purposes, but perceived to be limited in terms of their ability to contribute to decision making or instrument design.

It is therefore important to recognise that in real world case studies the research teams are considering this wide range of considerations *simultaneously*, and that although individual methods may have strengths and weaknesses for different purposes, methods are combined to address these different considerations.

3.3.2 Case study purpose is the primary driver

The purpose of the case study is the primary driver of the method selection. In Oslo study O1 where the primary aim of the sub project is to showcase monetary methodologies, "produces monetary outputs" is seen as a consideration across all methods. The same is seen with "monetary methods" and "strategic overview" in O2 where the focus on city-scale Green Infrastructure is key across all selected methods. Similarly in O3, where the focus was on developing mapping methods using ESTIMAP, the primary considerations are related to the "spatially explicit" nature of the approach and the fact that it is a "new method" and produces non-monetary output. However, in the Cairngorms study C1 where the focus was less on demonstrating the applicability of tools and more to document the value of specific areas to aid management decisions, method choices are each driven by different considerations.

3.3.3 Combining tools to address different considerations

The Cairngorms example demonstrates a clear example of different tools being used to address different considerations within a case study. In C1, the Focus Group is used to encourage a "systematic approach" and "cover multiple ecosystem services" in a way that "encourages stakeholder participation" and "encourages dialogue", but in a non-spatial way. Quickscan, used in the same meeting, (see Figure 2.4b) builds on this to address the additional considerations related to "spatial" elements and by facilitating the "inclusion of local knowledge". The Landscape Value Mapping and Photoseries methods used in the same sub-project build in information to address further considerations: the stakeholder-led desire for monetary outputs (Land Value Mapping) and the lack of information on cultural ecosystem services (Photoseries).

The intention here is not to suggest that this is a simple linear process (see section 3.2 for more detail on the complexity of method combination), but instead to flag that the existence of different considerations within a case study leads to methods being combined in ways that address these different concerns.

3.3.4 Drivers of method selection beyond the decision context

As highlighted in the full list of considerations, there are a number of factors outside of the research purpose that were also shown to influence method selection in real world case studies including: a) practical constraints (time/resources and data); b) research-related interests of the teams performing the research; and c) new opportunities and challenges within the case study.

Practical constraints (time/resources, data and expertise) tended to be most specifically mentioned with respect to the specific methods recognised to be quicker/less data intensive than others. Time/data was a consideration of either "definite" or "some" relevance in a number of instances of the selection of Participatory GIS and a "definite" consideration for the selection of Value transfer, Cost-Based methods, preference assessment, time use, expert-based mapping and photoseries

methodologies in at least two cases. In Barcelona (BARC), for example, limits in data availability and model scope led to soil erosion control being mapped with expert-based mapping, to combine with more sophisticated integrated mapping-modelling analysis of recreation and air quality using ESTIMAP. In addition, availability of expertise is a key factor both in terms of being able to identify methods which link best to the actual context-oriented problem and to be able to perform (technically) the required analyses.

Research-related issues also impacted on method selection, including factors such as the interests, expertise and motivations of the research team. The selection of monetary methods within Oslo's O1 and O2 sub-projects, and the Slovakian (TRNA) case's focus on the evaluation of the potential spatial landscape units provide ecosystem services, reflect the economic and landscape ecology focus of the cases' research teams. Additionally, the decision to move away from the focus on economic values within the Doñana Case study (DONN) reflects a recognised need from the researchers to take into consideration "lack of social and cultural aspects and stakeholder engagement" to address "ethical considerations". Similarly, a number of case studies identified that their interest in trialling a new method was a consideration when selecting an approach (e.g. O1, O2, C3). Furthermore, factors related to academic validity — such as a method being perceived as established and comparable — were also considerations when selecting a method.

 Making the most of "new opportunities" was commonly mentioned in the mind-maps as a factor that influenced method selection. This included factors such as the identification of *new funding opportunities* leading to a change in research focus: e.g. funding from the World Wildlife Fund (WWF) contributed to the focus of research in the Doñana case (DONN) on participatory scenario planning and deliberative mapping. Similarly the removal of funding streams will influence the pragmatic constraints mentioned above and influence choices towards approaches with lower resource requirements. *Changes in staffing* was another factor commonly highlighted by the case studies: the arrival of a new staff member could drive research in new directions. For example, in Sierra Nevada (SNNP), the arrival of a new PhD student with different skill sets facilitated the development of methods in combined socio-cultural and biophysical assessment (García-Llorente et al. 2015); PGIS (Palomo et al. 2013; García-Nieto et al. 2015) and spatial approaches such as InVEST (Palomo et al. 2014). In addition, access to *external expertise* often contributed to method choice. Exposure to, and support from, method experts within the OPENENSS consortium (see Fig 1a) led to a wider awareness of, and inclination to try new methods. In many cases these expert visits to case studies led to new opportunities developing within them, e.g. the development of ESTIMAP within both O3, C2 and other cases (e.g. Kenya (KEGA) and Barcelona (BARC) was facilitated by the visit of the ESTIMAP, whilst cases such as Trnava, Slocakia (TRNV) and Hungary (KISK) benefited from visits from the Quickscan team.

Some of the detailed aspects identified above will reflect the particular features of the OpenNESS project on which the research is based. However, the key messages: that practical constraints can limit method selection; that those performing the research will have their own agendas and interests which will influence which methods are prioritised; and that case studies are dynamic and need to take into consideration opportunities and constraints as they arise, are transferable to any ecosystem services assessment. They are important factors to consider, as they have significant implications on the outcomes of the research – and how it is / can be / should be used to influence policy and practice.

4. Discussion

4.1 Combining methods in Ecosystem Service assessments

4.1.1 Ecosystem service assessment is very do-able

There are a wide variety of tools available, and an increasing number of approaches to help users decide which tool to use (Chapter 1; Harrison et al, in press; OPPLA). Whilst individual tools are unlikely to address all the needs of a given context, this chapter demonstrates that by combining tools, case studies can work to better customise the information they collect to their needs. Echoing the findings of Chapter 3 and Jacobs et al., (in press), combining tools to access different aspects of a different study need not be prohibitively resource-expensive and/or may be a requirement for good management of the resource. However, there are many relatively simple tools (e.g. matrix approach, stakeholder card games) that can be used to kick-start an analysis, and be improved upon with more advanced techniques at later stages.

4.1.2 Flexibility and creativity are key

The range of methods applied within the OpenNESS case studies reflects not only the variety of methods available, but the need to customise methods to particular contexts. Contexts vary in terms of a wide range of factors including the type of issue they are trying to address; political and stakeholder factors related to the issue in question; the ecosystem services that are relevant; the priorities of the individuals doing the research (including e.g. disciplinary background and drive for academically novel research) and the availability of skills, time and resources to do the work. In addition, tools have different capabilities (both real and perceived) that make them more or less suitable for these different contexts.

Given this situation there is not, nor will there ever be, a one size fits all solution to ecosystem services assessment. However, the OpenNESS case studies show that by combining methods, allowing the methodologies to be adapted and evolved to match different contexts, and where necessary by creating new and hybrid methods drawing on the existing range of approaches it is possible to customise methods to each context. As such, one key take-home message from this chapter is that methodological flexibility should be seen as key tenet of ecosystem service assessment

4.2 The flip side of plurality

4.2.1 Where to start

It is beyond the scope of this chapter to provide definitive guidance on which tools to combine, as this will very much depend on the case study context. However, guidance is available on the capabilities of existing tools (see e.g. Chapter 1; Harrison et al., in press) and the case study experiences presented here suggest that when developing an ecosystem service assessment in a new context researchers should plan to build in a range of techniques to cover different aspects of the issue in question. Based on the experience of the OpenNESS case studies, a general recommendation would be:

> STEP 1) Start with an assessment of end user needs. This will almost always require the use of socio-cultural techniques (surveys, workshops etc.) and there are a number of tools that can be used within these to enrich the information content of the process (e.g. ES card game).

STEP 2) Use whatever combination of monetary, non-monetary, mapping and modelling methods are feasible to meet the customised needs of the case, whilst reflecting seriously on the importance of assessing the range of stakeholders whose needs should be considered and the range of different values that they may hold (see Chapter 3; Jacobs et al., in press).

STEP 3) Use an integrating approach to draw the different assessments together. This integrating approach need not be complex or numerical: it could be equally be a deliberative workshop with the relevant stakeholders drawing together the outputs from the different methods.

4.2.2 Issues of comparison and standardisation

Whilst it is clear that methodological plurality will be a necessary reality of ecosystem service assessment, particularly at local to regional levels, this clearly provides significant challenges for contexts that have a need for comparable, standardised approaches such as those at national or international levels (e.g. the EU MAES process (Mapping and Assessment of Ecosystem Services, Maes et al., 2013) the UN SEEA EEA (System of Environmental and Economic Accounts – Experimental Ecosystem Accounting, UNSD 2014). The process of integration can be greatly assisted by considering comparability in all contexts. This doesn't mean all projects should use standard approaches – but it does flag the importance of knowing how case study research can link to existing standards. Tools such as translation keys to link ES terminology used in case studies to standard ecosystem service lists (e.g. Common International Classification of Ecosystem Services: CICES), and the use and development of transferable methods (such as InVEST, ESTIMAP) may assist with this.

5. Conclusion

This chapter has demonstrated the range and variety of methods applied in ecosystem service assessment studies in 26 European case studies across a wide range of contexts. It has highlighted the ways in which methods can be combined, and identified the range of considerations addressed when selecting methods to use. Whilst the complexity of environment and the varied challenges of management mean that best managing the world's ecosystem services is no small task, the case studies presented here demonstrate that the tools to assess ecosystem services exist and that by combining methodologies in innovative and creative ways ecosystem service methods can be customised to address case study needs. Most importantly, by learning from the experiences of others (e.g. via the OPPLA hub), and by including those with a stake in the problem to be solved we can ensure that these innovative approaches diffuse quickly to give us the best chance of sustainably managing the services our ecosystems provide.

6. Epilogue

Chapter 2 was peer reviewed for publication in the journal Ecosystem Services and updated and improved in response to reviewers comments. Section 3.1 above, on which methods were combined and section 3.3 on the reasons for method combination were considerably expanded with new quantitative and qualitative material. This material included enhanced statistical analysis of the core data to draw out stronger messages as to the ways that methods were combined in practice by looking at six overarching factors that the case studies highlighted as their reason for combining methods: 1) a need to assess a range of different ES beyond those possible with a single method; 2) a need to assess different elements of the ES cascade, i.e. to look at both supply and demand, or at different

elements of ecosystem structures, functions, services, benefits or values; 3) a need to assess different aspects of value (biophysical, socio-cultural, monetary) within a case study; 4) a need to engage with different types of stakeholder; 5) a need to address methodological concerns relating to the use of a single method (e.g. to increase robustness, for validation); and 6) selecting methods to address different stages of the research/case study's development. The role of spatial scale and the level of biophysical realism of the methods as factors influencing method choice were also considered in greater detail. In addition to this, further qualitative detail on each case study's approach, as short commentaries addressing key questions related to method selection were added to the supplementary material. Furthermore, to increase clarity over ways that methods are combined (Section 3.2 above) a new diagram was developed and the types of method combination were amalgamated into four main classes: methods linked by 1) inputs-outputs; 2) learning - which includes learning across cases and embedded within individuals 3) linkages through model development - which includes both ongoing improvements in methods and hybridisation of approaches and 4) triangulation - where different approaches are compared to get better understandings of the same topic. Finally, drawing on the enhanced analysis allowed clear take home messages to be presented. These messages will allow those looking at combining methods for ES assessment in the future to do so drawing on the rich, diverse experiences of the OPENNESS cases.

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Supplementary materials

Case study name	Code	Brief description
Helsinki	SIBB	Operationalising ecosystem services in urban land-use planning in Sibbesborg, Helsinki Metropolitan Area, Finland
Slovakia	TRNA	Landscape-ecological planning in the urban and peri-urban areas of Trnava, Slovakia
Oslo	OSLO	Valuation of urban ecosystem services in Oslo, Norway
France	ALPS	Operationalising ecosystem services in regional and national forest management planning in the multifunctional landscape of the French Alps
Carpathians	CAPM	Forest management in the Carpathian Mountains, Romania
Germany	BIOG	Bioenergy production in Saxony, Germany
Cairngorms	CNPM	Improved, integrated management of the natural resources within the Cairngorms National Park, Scotland
Sierra Nevada	SNNP	Ecosystem services in the multifunctional landscape of the Sierra Nevada, Spain
Warwickshire	WCSO	Tools for investigating biodiversity offsetting in Warwickshire, England
Hungary	KISK	Supporting sustainable land use and water management practices in the Kiskunság National Park, Hungary
Belgium 1	CRKL	Reconciling land consolidation and multifunctional agricultural landscapes: Project De Cirkel (Limburg, Belgium)
Italy	GOMG	Nature-based solution for water pollution control in Gorla Maggiore, Italy
Loch Leven	LLEV	Quantifying the consequences of the European water policy for ecosystem service delivery at Loch Leven, Scotland
Romania	DANU	Operationalising ecosystem services for an adaptive management plan for the Lower Danube River, Romania
Belgium 2	STEV	Integration of ecosystem services in the planning of a flood control area in Stevoort, Belgium
Donana	DONN	Operationalization of ecosystem services in the cultural landscapes of Doñana, south-west Spain
Portugal	SACV	Operationalising ecosystem services in the Sudoeste Alentejano e Costa Vicentina Natural Park, Portugal
Essex	ESSX	Ecosystem service mapping in Essex, England
India	BKSU	Participatory biodiversity management for ecosystem services in Bankura and Sundarbans, India
Kenya	KEGA	Operationalising ecosystem services for improved management of natural resources within the Kakamega Forest, Kenya
Patagonia	SPAT	Retention forestry to improve biodiversity conservation and ecosystem services in Southern Patagonia, Argentina
Brazil	BIOB	Biofuel farming and restoration of natural vegetation in the São Paulo region, Brazil
Barcelona	BARC	Mapping ecosystem services to inform landscape planning in the Barcelona metropolitan region, Spain
The following case studies reported only one method and so excluded from the analysis in section 3:		
Finland	BIOF	Forest bioenergy production in Finland
Waddensee	WADD	Ecosystem services in coastal management, Wadden Sea, the Netherlands
Vitoria-Gastiez	VGAS	A Green Infrastructure strategy in Vitoria-Gasteiz, Spain

SM2.1: Overview of the 26 OPENNESS case studies within this chapter

Ecosystem service focus	Types of Service	My interest in the following types of ES drove my method selection: …Provisioning ES
		…Regulating ES
		…Supporting ES
		…Cultural ES (quantifiable)
		…Cultural ES (intangible)
		…Range of ES
	Supply and/or Demand	Interested in ... ES supply
		…ES demand
Decision context		Purpose is … exploring the ES concept
		… providing Information on ES
		… making decisions around ES
		…designing policy instruments around ES
Pragmatic constraints		We had access to the expertise with method … in the Case Study
		… in the OPENESS consortium
		We chose this method as we were constrained by … data
		…time
		…budget
Research related considerations		We were interested in trialling a new method
		The method would be comparable with work done elsewhere
		The method is well established
		We needed to develop a new method
Methodological aspects	Uncertainty	We needed a method that …addresses uncertainty
	Spatial aspects	… is spatially explicit
		… can assist with detailed spatial planning (fine scale)
		… can provide a strategic overview (broad scale)
		… is applicable across spatial scales
	Temporal aspects	… is applicable across temporal scales (e.g. time-series)
		… can explore future scenarios
	Synergies, trade-offs and conflicts	The method … covers many ecosystem services
		…allows trade-offs
		…encourages system-level understanding
	Need for monetary/ non-monetary output	… produces monetary output
		…produces non-monetary output
	Encouraging stakeholder involvement	… encourages stakeholder participation
		… facilitates the inclusion of local knowledge
		…encourages dialogue
	Presenting a clear message	… has a methodology that is easy to communicate to stakeholders
		…has results that are easy to communicate results to stakeholders
Stakeholder co-creation		The stakeholders …chose the method themselves
		…were involved in the selection of the method

Figure SM2.2: Method selection considerations addressed within the questionnaire Q2 – see Fig 2.2 main text.

Figure SM2.3 — Methods used within the OPENNESS projects (matrix of methods × sites)

Column headers (left to right): Oslo (OSLO), Doñana (DONN), Hungary (KISK), Sierra Nevada (SNNP), Slovakia (TRNA), Carpathians (CARM), Cairngorms (CNPM), Portugal (SACV), Barcelona (BARC), Patagonia (SPAT), Kenya (KEGA), Romania (DANU), Germany (BIOG), Warwickshire (WCSO), Belgium (ORKL), Italy (GOMG), Loch Leven (LLEV), Essex (ESSX), France (ALPS), Brazil (BIOB), Belgium (STEV), Helsinki (SIBB), India (BKSU), Vitoria-Gasteiz (VGAS), Finland (BIOF), Waddensee (WADD), TOTAL

Category	Method	TOTAL
Biophysical modelling	SITE land use model	2
	State and Transition Models	2
	Climate envelope modelling	2
	Hydrological models	1
	Ecological models	1
	Statistics	1
Integrated mapping-modelling approaches	ESTIMAP	11
	InVEST	2
	Integrated mapping-modelling approaches	1
Expert-based mapping	Matrix approach based on land use data only	5
	Matrix approach based on multiple datasets	2
Participatory Mapping approaches	Public Participatory GIS (PPGIS)	7
	QuickScan	4
	ECOPLAN – QuickScan	3
	Blue-green factor / BGApp	3
	Deliberative mapping (group-based)	1
	ESM-App / MapNat	1
	Participatory mapping approaches	1
Non-monetary valuation	Preference assessment	12
	Photo-series analysis	11
	Narrative analysis	5
	Time use	3
	Deliberative valuation	3
	Photo-elicitation surveys	3
	Q-method	1
	Non-monetary valuation	1
	Choice experiment	1
Monetary valuation	Cost-based	6
	Value transfer	3
	Stated preference	3
	Revealed preference	1
	Monetary valuation	1
Integrative approaches	Scenario development	5
	Multi-Criteria Decision Analysis (MCDA)	5
	Bayesian Belief Networks (BBN)	6
	Meta-analysis approach	1

Column totals (bottom row): 14, 10, 8, 8, 6, 6, 6, 6, 5, 5, 4, 4, 4, 4, 4, 4, 4, 4, 3, 3, 2, 2, 2, 1, 1, 1

Figure SM2.3: Methods used within the OPENNESS projects including detail on method combinations; white circles indicate a single method; black circles indicate more than one method of the same type.

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Chapter 3 - The means determine the end – pursuing plural valuation in practice

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Chapter overview

In environmental valuation, although it is well recognised that the choice of method heavily affects the outcome of a valuation, little is known about how existing valuation methods actually elicit the different values. Through the assessment of real-life applications of valuation, this chapter tracks down the suitability of 21 valuation methods for 11 value types and assesses the methodological requirements for their operationalization. We found that different valuation methods have different suitabilities to elicit diverse value-types. Some methods are more specialized than others, but every method has blind spots, which implies risks for biased decision-making. No single valuation method is able to capture the full spectrum of values of nature. Covering the intrinsic, relational and instrumental value dimensions requires careful selection of complementary valuation methods. This chapter also demonstrates that performing such an integrated valuation does not necessarily entail more resources, as for every value dimension, methods with low to medium operational requirements are available. With this chapter, we aim to provide further guidance on selecting a complementary set of valuation methods in order to develop integrated valuation in practice that includes values of all stakeholders into environmental decision-making.

Chapter Keywords

Published article

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"The end cannot justify the means, for the simple and obvious reason that the means employed determine the nature of the ends produced" - Aldous Huxley

1. Introduction

The policy relevance of valuation of nature is reflected in international initiatives such as the Millennium Ecosystem Assessment (MA 2005), The Economics of Ecosystem services and Biodiversity (TEEB, 2010), the Strategic Plan for Biodiversity and the first CBD Biodiversity Target which aims at raising awareness on the value of biodiversity (SCBD, 2010). More recently, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has developed a guide to assess the multiple values of nature and its benefits, in order to acknowledge these in all ongoing regional, global and thematic IPBES assessments (IPBES 2015). In addition, as values are shown to be the main drivers of sustainable behaviour (e.g. Ajzen, 1991; Schultz, 2011; Clayton et al., 2013), the way we value nature will directly impact achievement of the Sustainable Development Goals.

The dependence of our societies on nature has been well known and valued throughout history (Daily, 1997, pp. 5–6), although the field of environmental valuation is relatively young (e.g. Ridker and Henning, 1997). Already since the 1970s, different scholars emphasized the controversies, risks and limitations of environmental valuation relying on one value type only (typically economic value; e.g. Kapp, 1972; Pearce, 1976, Westman, 1977, Martinez-Alier, 1987; see Baveye et al., 2013 for an overview). Since the 1990s, monetary valuation has resurged due to its potential contribution to environmental decision-making (Bateman et al., 2013); although some authors have argued that its impact for influencing decision-making is still deficient (Laurans et al., 2013, Laurans and Merme, 2014). As a consequence, original criticisms have been revived in an equally growing body of literature which argues that monetary valuation fails to capture the importance of nature beyond economic values (e.g. Martinez-Alier et al., 1998; Chan et al., 2012; Dendoncker et al., 2014; Boeraeve et al., 2015; Gómez-Baggethun and Martín-López, 2015). In fact, valuation approaches that target single value-types, be they economic, ecological or socio-cultural values, can only represent part of the society and its worldviews, interests and preferences. As a response, integrated valuation approaches are increasingly put forward (Dendoncker et al., 2014, Martín-López et al., 2014; Jacobs et al., 2016).

Integrated valuation recognises that valuing nature to inform more sustainable decisions requires a broader definition of 'value' and 'valuation', and the inclusion of a plurality of values in decision-making. This realization is reflected in the growing critical mass of scientists from different disciplines engaging in the integrated valuation field (Jacobs et al., 2016). Instead of focusing on differences, critiques and academic opposition of single methods or schools, integrated valuation seeks to combine diverse approaches and methods, understand interdisciplinary differences, acknowledge different knowledge systems and interests of multiple social actors, and provide guidelines to integrate plural values in real-life decisions and problem solving (Gómez-Baggethun et al., 2014; Gómez-Baggethun and Martín-López, 2015). This emerging field of integrated valuation has percolated into various global science-policy interface initiatives such as IPBES (IPBES 2015, Jacobs et al., 2016; Pascual et al., in press).

The scientific understanding of the multiple ways by which different societies acknowledge and interpret the importance of nature has resulted in different value definitions, conceptions and

categorizations (Kenter et al., 2015; Arias-Arévalo et al., in press, see table 3.1). In this chapter, three categorizations are applied. Within the traditional economic understanding of value, the Total Economic Value (TEV) framework classifies values into use and non-use values (Krutilla, 1967; Turner et al. 2003). Use values include direct use, indirect use, and option values while non-use values refer to satisfaction that individuals derive from the existence of environmental assets per se, or from the pleasure for others or future generations (Plottu and Plottu 2007). In ecological economics literature on ecosystem services (e.g. Farber et al., 2002; de Groot et al., 2010; Dendoncker et al., 2014; Martín-López et al., 2014) and in the TEEB project, values are classified into three value domains: ecological, sociocultural and monetary (Gómez-Baggethun and Martín-López, 2015).

Recently, IPBES adopts an even more inclusive approach for defining and categorizing values, by broadening the concept of value in terms of 'importance, worth or usefulness' , as well as 'principles and moral duties' (Díaz et al., 2015). The IPBES classification of values distinguishes three value dimensions: an intrinsic dimension, an instrumental dimension and a relational dimension (IPBES, 2015; Pascual et al., in press, table 3.1). Whereas the intrinsic dimension covers values of nature itself that are non-anthropocentric (Díaz et al., 2015). The instrumental dimension includes all the aforementioned use value types and are typical related with provisioning and regulating services, whilst the relational dimension refers to desirable relationships among people and between people and nature, being more associated with cultural ecosystem services (Chan et al., 2016).

Table 3.1. *Value classification according to three frameworks. Sources: Krutilla (1967); Farber et al. (2002); Turner et al. (2003); de Groot et al. (2010); Dendoncker et al. (2014); IPBES (2015); Díaz et al. (2015).*

Framework	Category	Short definition
Total Economic Values (TEV)	Direct use values (e.g. provisioning services)	Value derived from conscious use and enjoyment of nature, both extractive (e.g. wood, food) and non-extractive (e.g. tourism, appreciation of landscapes)
	Indirect use values (e.g. regulation of air pollution)	Value associated with regulating services, such as pollination, water purification or soil fertility, not necessarily entailing consciousness in their use
	Option values (e.g. preservation of forests for future use and other values)	Value associated with the potential to use and enjoy nature in the future
	Bequest values (non-use, e.g. natural heritage and cultural heritage for future generations,...)	Satisfaction that humans derive from the knowledge that future generations will use or enjoy nature

Framework	Category	Short definition
	Existence values (non-use, e.g. existence of diverse species and ecosystems)	Satisfaction derived by humans from the knowledge that nature (in its multiple forms) exists
TEEB values	Ecological values (e.g. resilience, biodiversity or functioning ecosystem,...)	Nature's capacity to provide ecosystem services (de Groot et al., 2002), related to resilience of ecosystems to ensure provision of services over time (Pascual et al., 2010)
	Sociocultural values (e.g. heritage, sense of place or spirituality)	Contributions of nature to cultural identity, sense of belonging, heritage, spirituality or sacredness, good social relationships derived from the use, enjoyment or management of nature (Chan et al., 2012; Martín-López et al., 2014)
	Monetary values (e.g. jobs, profits, costs or investments)	Contributions of nature to individual welfare, conceived as utility and represented through monetary metrics (Martín-López et al., 2014)
IPBES values	Intrinsic value dimension	Inherent value of nature, independently of any human judgement (Callicot, 1987; IPBES, 2015)
	Instrumental value dimension	Benefits of nature, contributions of nature to the achievement of human's quality of life (Díaz et al., 2015; IPBES, 2015)
	Relational value dimension	Good quality of life, desirable relationships among people and between people and nature (IPBES, 2015, Chan et al., 2016)

Because valuation methods have been designed to elicit particular value-types, they provide very specific information and reveal importance of biodiversity and ecosystem services in different ways (Martín-López et al., 2014). This points to the need to consider multiple methods in order to properly acknowledge the diversity of forms by which people value nature (Martín-López et al., 2014; Díaz et al., 2015, Gómez-Baggethun et al., 2016; Jacobs et al., 2016). However, there is only sparse information on the suitability of different methods to capture different values (e.g. Martín-López et al., 2014; Smith et al., 2016) or on their application in real-life practice (e.g. Bagstad et al., 2013).

This chapter aims to provide guidance for selecting a set of valuation methods which is both appropriate and realistically applicable to elicit the diversity of values associated with nature. Specifically, we (1) assess the suitability of 21 monetary, socio-cultural (also called non-monetary; e.g. Gómez-Baggethun and Martín-López, 2015), biophysical and synthesising methods to uncover the different value-types (sensu IPBES, TEEB and TEV, Table 3.1) and (2) assess the methodological requirements (in terms of resources, data and collaboration) for their application. This is the first comparative study which evaluates suitability of different methods to elicit various value dimensions in practice and assesses requirements for implementing integrated valuation that allows the consideration of multiple value dimensions.

2. Methods

2.1. Data collection

First, a survey template was developed to describe and assess the methodological requirements and appraise the suitability of 21 methods to elicit multiple values (sensu IPBES, TEEB and TEV). This sample of methods is a subset from the tools applied in the OpenNESS project (http://www.openness-project.eu/) and the main selection criterion was pragmatic: availability of eligible and responsive valuation experts with hands-on experience in the method.

In the survey template, one tabulated question evaluated how each method is estimated as suitable to elicit a range of value types (Table 3.1). Other questions asked information about the amount of new quantitative and qualitative data required, the degree of collaborations required with scholars from other fields and with non-academic stakeholders, as well as the demand in time and economic resources. We then synthesized the general level of requirements as the sum of the scores of (1) the need of new data, (2) the need of collaboration with scholars from other disciplines and with non-academic experts and (3) the level of time and economic resources for applying each method.

17 experts[6] who had actively applied various methods in real-life contexts filled in the survey, based on their previous and current application of the method in concrete case study contexts. Because some of the experts have knowledge and experience in multiple methods, they completed the survey for more than one method. For each socio-cultural and synthesising method, two experts completed the survey, while biophysical and monetary valuation methods were filled in by one expert only. After the experts filled in the survey, we validated responses by asking two reviewers per method to revise and complete the information provided by experts. Reviewers independently went through the information provided by experts. When disagreement emerged, a round of discussion was implemented in order to reach consensus. Final data used in this chapter results from various validation rounds between the experts and the reviewers.

For the purpose of this chapter, we grouped valuation methods in 4 groups according to the object of their valuation or the main units used (table 3.2, see also Harrison et al., *in press*). Biophysical valuation methods aim to appraise ecosystem condition and/or capacity of ecosystems to provide ecosystem

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[6] Authors of this chapter.

services. Socio-cultural and monetary valuation methods target the social interest or demand for diverse values (Martín-López et al., 2014). Socio-cultural valuation aims to uncover the contribution of nature to human well-being, by eliciting human preferences beyond strictly monetary measurements; whereas monetary valuation methods use monetary units to elicit these preferences. Finally, synthesising methods aim at bringing together different types of information to support decision-making (Table 3.2). Appendix B provides a more elaborated description of methods (see also Harrison et al., *in press*).

Table 3.2. Overview of the valuation methods considered in this chapter according to the four groups of methods: biophysical, socio-cultural, monetary and synthesising valuation methods. Methods are alphabetically ordered in each of the methodological groups. For a detailed description of methods, see Appendix B, and for a short description of methods see Harrison et al. (in press).

Method	Examples of applications in ecosystem service assessments
Biophysical valuation methods	
MapNat App	An ecosystem service mapping application for Android smartphones (Priess et al., 2014)
Spreadsheet-type methods (a.k.a. matrix method)	Burkhard et al. (2012, 2014), Jacobs et al. (2014), Kopperoinen et al. (2014, 2016)
State and transition models	Bestelmeyer et al. (2010); Kachergis et al. (2011)
Socio-cultural valuation methods	
Cards game method	A method that combines photo-elicitation with a rating exercise (Demeyer, 2014)
Narrative method	de Oliveira and Berkes (2014); Klain et al. (2014)
Participatory mapping method, a.k.a. participatory GIS (PGIS) and Public Participation GIS (PPGIS)	Fagerholm et al. (2012); Palomo et al. (2013); Plieninger et al. (2013a); García-Nieto et al. (2014); Kopperoinen et al. (2016)
Photo-elicitation survey	García-Llorente et al. (2012a); López-Santiago et al. (2014)
Photo-series analysis (a.k.a. geotagged photo-analysis)	Casalegno et al. (2013); Martínez-Pastur et al. (2016); Tenerelli et al. (2016)
Preference assessment survey	Martín-López et al. (2012); Iniesta-Arandia et al. (2014); Oteros-Rozas et al. (2014)
Time use method	Higuera et al. (2013); García-Llorente et al. (2016)

Method	Examples of applications in ecosystem service assessments
Monetary valuation methods	
Benefit transfer	Johnston et al. (2015); Navrud and Ready (2007)
Cost-based methods	BBOP (2009); Saarikoski et al. (2016)
Hedonic pricing method	Garrod and Willis (1992); Barton et al. (2015)
Production function method	Losey and Vaughan (2006)
Shadow pricing method	Bekele et al. (2013); Polaski et al. (2011); Schröter et al. (2014)
Stated preferences method, which includes contingent valuation and choice modelling	Barkmann et al. (2008); García-Llorente et al. (2012a,b); Hanley et al. (1998); Lindhjem (2007)
Travel-cost method	Clawson and Knetsch (1968); Lankia et al. (2015); Martín-López et al. (2009); Termansen et al. (2013)
Synthesising valuation methods	
Bayesian belief networks	Barton et al. (2012); Gonzalez-Redin et al. (2016); Landuyt et al. (2013)
Deliberative valuation method	Kaartinen et al. (2013); Kelemen et al. (2013); Kenter et al. (2011); Raymond et al. (2014)
Multicriteria decision analysis	Kiker et al. (2005); Mendoza and Martins (2006); Saarikoski et al. (2016)
Scenario planning method	Oteros-Rozas et al. (2013), Palomo et al. (2011); Plieninger et al. (2013b); Ravera et al. (2011)

2.2. Data analysis

The method suitability responses were explored by principal component analysis (PCA, Dray and Dufour 2007). To this end, the response categories were coded numerically. The analysis explored patterns in (estimated) value-capturing suitability between all methods. The data was organized into a 21 methods x 11 value types matrix. The explanatory power of this analysis is reflected in the percentage of variance explained by the components (axes), whilst the correlation between value types can be read from the alignment of their vectors. R package ade4 (Dray and Dufour 2007) was used to conduct the PCA. We then synthesised the suitabilities for all methods per group (i.e. biophysical, socio-cultural, monetary and synthesising methods) to elicit suitability for IPBES value dimensions specifically (vectors a, b and c in Figure 3.1A).

3. Results

3.1. Diverse value types and dimensions

The PCA firstly provides some insight regarding the level of similarity between suitabilities to elicit value types (Figure 3.1A), and how they relate to IPBES value dimensions. Second, the pattern elicits which (groups of) methods are more or less suitable to cover the entire value spectrum (Figure 3.1B). The alignment of value types and dimensions is presented along the PCA-axes (Figure 3.1A). The X-axis (which explained 40% of variance) shows that intrinsic and relational values ('*a' and 'c'* in Figure 3.1A.) correlate with socio-cultural, existence, option, bequest and ecological value types. In fact, the X-axis depicts a suitability gradient from right to left, eliciting multiple value-types, except for the bundle of values associated with the instrumental value dimension, i.e. instrumental ('*b'),* direct use ('*g'),* indirect use ('*h'*) and monetary values ('*f'*) (Figure 3.1A). This bundle representing the instrumental value dimension is thus determined by the Y-axis (20% of variability).

3.2. Method suitability to elicit values

The grouping of different methods demonstrates that the studied biophysical valuation methods are least suitable to capture multiple values, although some might be more suitable to capture the intrinsic value dimension, e.g. MapNat ('*g'*) (Figure 3.1B). Here, it is also important to point out that despite the original classification of photo-series analysis ('*j'*) as a socio-cultural valuation method because its capacity to represent social preferences of cultural ecosystem services (e.g. Casalegno et al., (2013); Martínez-Pastur et al., (2016)), its capacity to relate cultural ecosystem services with ecological properties (e.g. Martínez-Pastur et al., (2016); Tenerelli et al., (2016)) supports the idea that it can also be grouped as biophysical valuation method. In fact, it seems that the suitability of photo-series analysis to elicit values is more related to other biophysical valuation methods, rather than socio-cultural.

Monetary valuation methods seem mainly suitable to elicit values in the instrumental dimension, although some were considered suitable to elicit values in the intrinsic value dimension, e.g. stated preference methods ('*q'*) (Figure 3.1B). Socio-cultural valuation methods were considered highly suitable to elicit most of the assumed 'intangible' values in the relational value dimension. Synthesising valuation methods, being dependent on input from other methods, seem to be suitable to elicit value types in both the instrumental and relational value dimensions, as well as in the intrinsic value dimension.
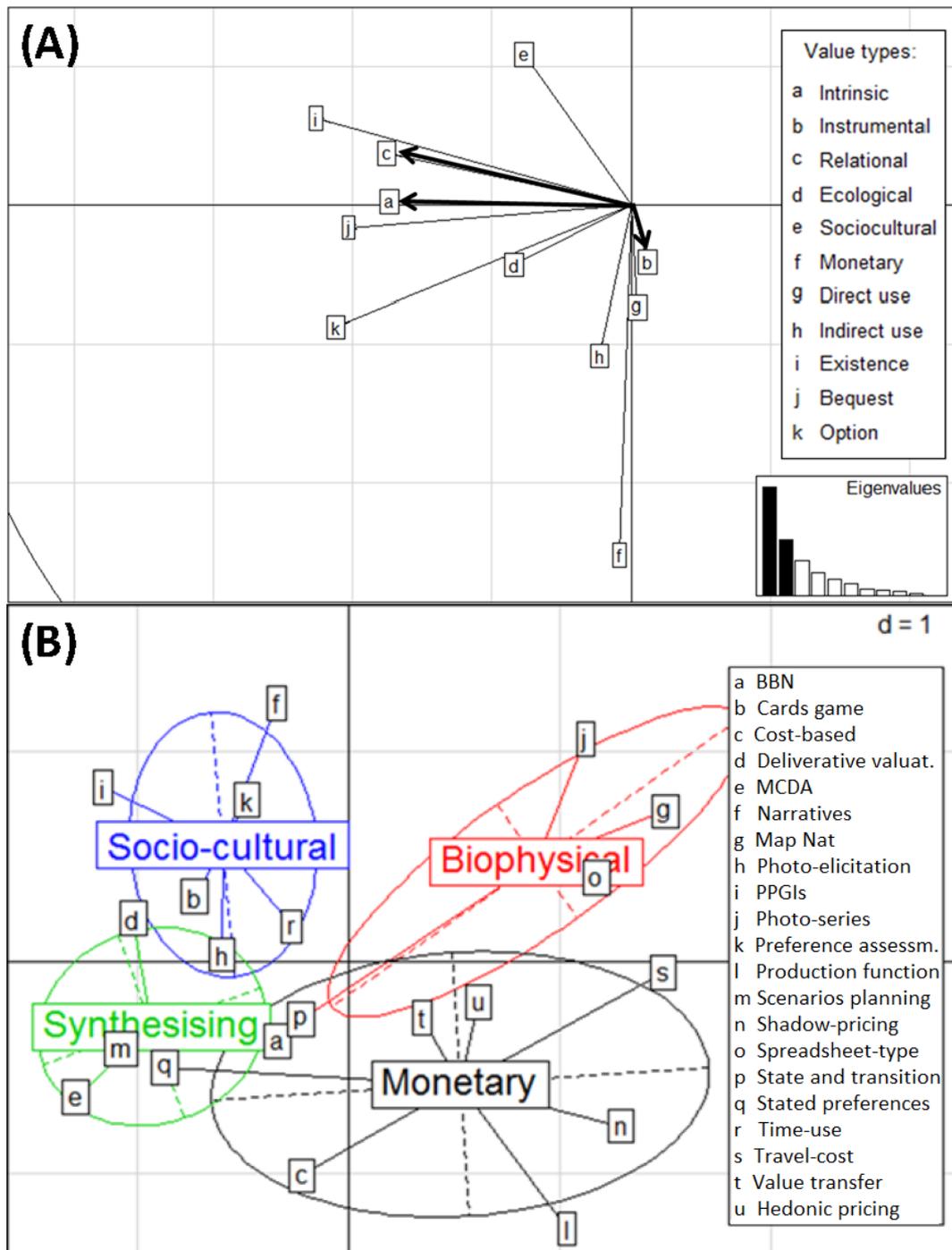
Figure 3.1. *PCA analysis of the suitability of 21 valuation methods to capture 11 value types. A: correlation circle of PCA using all surveyed value types (see Table 3.1). B: Methods' positioning on the PCA, grouped in biophysical, socio-cultural, monetary and synthesising methods. Explained variance X-axis 40%, Y-axis 20%. (BBN = bayesian belief networks; MCDA = multicriteria decision analysis; PPGIS = Participatory mapping). Photo-series analysis (j) as a crosslinking socio-cultural /biophysical valuation method has been considered biophysical in this analysis.*

Total coverage of IPBES value dimensions by all the methods is summarized in Figure 3.2. This representation clearly demonstrates that to cover all three value dimensions with a set of methods, ideally methods from all groups should be selected, especially since methods from the synthesising category depend on input from other methods.
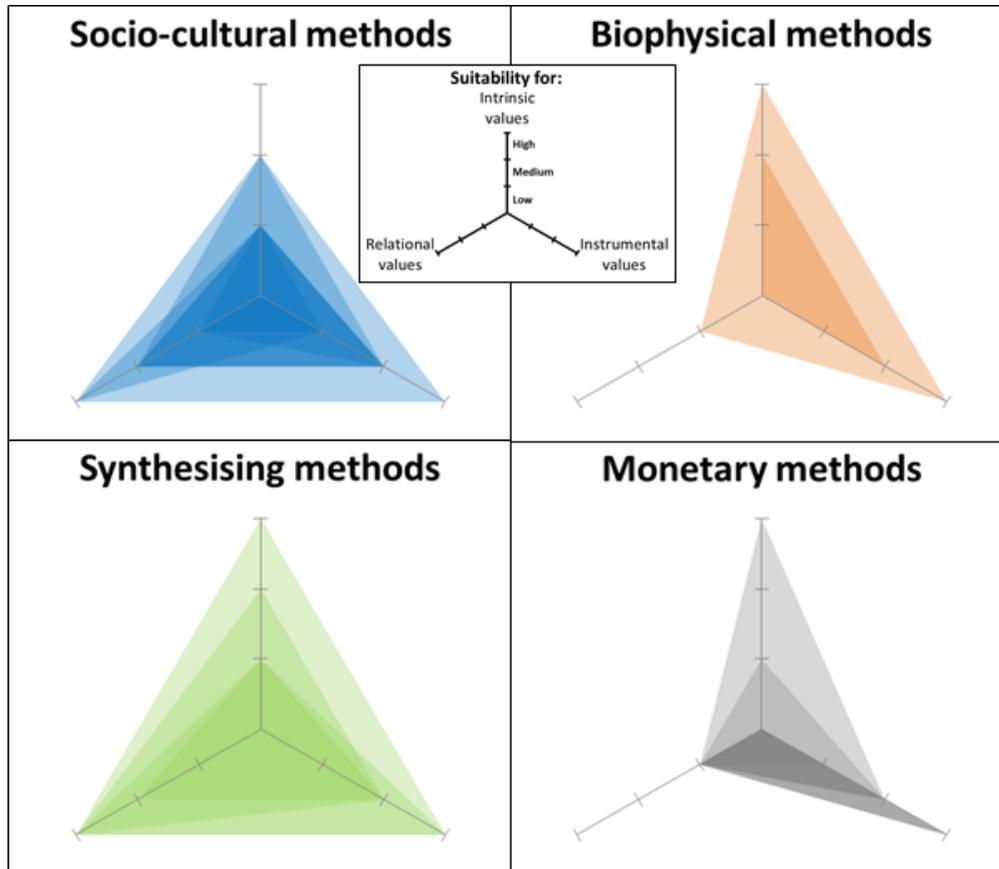
Figure 3.2. *Suitability of studied groups of valuation methods to elicit the three main IPBES value dimensions: i.e. intrinsic, relational and instrumental values. Color grading represents increasing number of methods (darker means more methods).*

3.3. Requirements for method application

Overall, the group of socio-cultural valuation methods was assessed as the one with the highest level of methodological requirements, particularly in terms of more data (Figure 3.3). In fact, the most important requirement of socio-cultural valuation methods relies on the need for new quantitative or qualitative data. Synthesising valuation methods were assessed as the most demanding for the requirements of collaboration with scientists of other disciplines and non-academic stakeholders (Figure 3.3). Finally, the most demanding methods in terms of economic and time resources were monetary valuation tools (Figure 3.3).

Despite the high methodological requirements for the application of specific methods, at least one method in each of the four groups of methods –i.e. biophysical, socio-cultural, monetary and synthesising - was assessed to have low or medium level of general application requirements (Figure 3.3).

	DATA	COLLABORATION			RESOURCES		
	Amount of data	Researchers own field	Researchers other field	Non-academic stakeh.	Time	Economic	General level of requirement
Biophysical valuation methods							
MapNat App	◕	●	●	●	◔	◔	
Spreadsheet-type method (basic)	◐	●	●	●	◔	◔	
Spreadsheet-type method (advanced)	●	●	●	●	◐	◐	
State and transition models	◐	●	○	●	◔	◐	
Socio-cultural valuation methods							
Cards game method	◕	○	●	●	◔	◔	
Narrative method	●	○	○	●	◐	◐	
Photo-elicitation survey	●	●	●	○	◐	◐	
Photo-series analysis	◕	●	●	○	◔	◔	
Participatory mapping method	●	○	●	●	◐	◐	
Preference assessment survey	●	●	●	○	◐	◐	
Time use methods	●	●	○	●	◐	◐	
Monetary valuation methods							
Benefit transfer	◐	●	○	○	◔	◔	
Cost-based methods	◐	●	○	○	◔	◔	
Hedonic pricing method	●	○	●	○	◐	◐	
Production function method	●	○	●	○	◐	●	
Shadow-pricing method	◐	○	●	○	◔	◔	
Stated preferences methods	●	●	●	○	◐	●	
Travel-cost method	●	●	○	○	◐	◐	
Synthesising valuation methods							
Bayesian beliefs networks	◕	○	●	●	◔	◐	
Deliberative valuation methods	◕	○	●	●	◐	◐	
Multicriteria decision analysis	◕	●	●	●	◔	◐	
Scenario planning method	●	●	●	●	◔	◐	

Figure 3.3. Methodological requirements for valuation methods, classified in the four groups: biophysical, socio-cultural, monetary and synthesising methods. Methods are alphabetically ordered in each of the methodological groups. Methods were assessed according to the level of requirements in terms of data, time and economic resources (= high, ◕ = medium-high, ◐ = medium-low, ◔ = low and ○ = no particular requirement). Collaboration was assessed as (● = collaboration required; ○ = collaboration not necessarily required). General level of requirements is indicated by the 'wifi signal' bars. We distinguished between two different applications of the spreadsheet-type method: basic spreadsheet approach based on land-use data and advanced spreadsheet approach based on multiple datasets (e.g. GreenFrame); for more details, see Harrison et al. (in press).

4. Discussion

This chapter uses real life application expertise to verify whether valuation methods differ in suitability to elicit values of nature and how they differ in practical application requirements. Valuation of nature requires an integrated approach (Jacobs et al., 2016), but resources (time, budget, data or collaborations with other scholars and stakeholders) can be restricted in practice. Our study aims to

provide some insights for the selection of valuation methods in order to represent multiple value dimensions in an effective but efficient manner, which is one of the main principles to achieve integrated valuation (Gómez-Baggethun et al., 2014; Gómez-Baggethun and Martín-López, 2015) .

This chapter demonstrates the fact that different valuation methods are more or less suitable to elicit specific value types and dimensions (Figure 3.1). In fact, this chapter reconfirms that valuation methods can act as value-articulating institutions (Vatn and Bromley, 1994, Vatn, 2005; Chapter 4 and Barton et al., *in press*), *creating* a value rather than *eliciting* a pre-existing value. In other words, '*the means employed determine the nature of the ends produced*' (A. Huxley). This realisation supports former studies that argue that -as a practical implication- the selection of the valuation method might be as relevant as the valuation result itself (Gómez-Baggethun and Ruiz-Pérez, 2011; Martín-López et al., 2014).

As the choice of the valuation method can strongly determine the value-dimension that will be elicited ('creating'), valuation practice should consider different, complementary and diverse methods in order to adequately cover the distinct ways by which people value nature and its contributions to human well-being. More precisely, in order to represent the diversity of nature's values held by different social actors in decision-making, integrated valuation should entail *as much diversity* of methods *as value plurality* exists in the system (Martín-López et al., 2014). In consequence, integrated valuation cannot be done by a single method (even if it is a synthesising one) or by methods from the same group of methods.

Our study suggest that selection of a set of methods from each of the four method groups allows elicitation of all value dimensions. The study also demonstrates that for each group of valuation methods, there is at least one method that can be reasonably applied with few resources and methodological requirements (Figure 3.3). In other words, it is possible to elicit multiple dimensions of value without spending excessive resources in a research or assessment project.

Dealing with complexity in environmental valuation may involve higher initial information costs than valuations that narrowly focus on single value types (Chapter 4 and Barton et al., *in press*). In addition, Martinez-Alier and Muradian (2015) argue that integrated valuation involves higher complexity of communication and methodological development. However, it is important to note that, although a single-method valuation can seem more cost-efficient, its reduced capacity to provide information about multiple values and the risks this involves for decision-making in real human-nature contexts entails that such valuations are *de facto* inefficient and ineffective. Indeed, Ockham's razor or the parsimony principle states that the best out of two good solutions is the simpler one. Therefore, the application of integrated valuation application should strike the balance: the number of values and elicitation methods should be enough to elicit the main value dimensions that exist in a system in a fair and just process, but at the same time be kept at the minimum level required to meaningfully understand the problem at stake.

Some caution should be taken when selecting methods from the different groups with the purpose to provide input for develop an integrated valuation. First, covering all the value dimensions might require methods that are ontologically and epistemologically very different and represent conflicting valuation languages (Arias-Arévalo et al., 2017). In this sense, integrated valuation in its true sense

should acknowledge the incommensurability of values: some values can be neither comparable to each other, nor to an ultimate single-value indicator (Martínez-Alier et al., 1998; O'Neill et al., 2008). For the sake of comparability, narrow interpretations of 'integrated' valuation, 'integrate' values into a single (numeric) unit. This holds the risk of reducing the distinct ways of expressing values (e.g., qualitative or quantitative) and the inherent value pluralism. Integrated valuation rather accepts (and emphasizes) these diverse values and languages, in order to truly consider them in decision-making.

A second point of caution concerns the claim that valuation of nature promotes inclusion of the different voices and interests of multiple social actors in decision-making (Menzel and Teng 2010; Martín-López and Montes, 2015). Indeed, the use of single-method approaches might invoke that other valuation dimensions are overlooked and that the people who embrace these values are also neglected in decision-making (Brondizio et al. 2010; Jax et al. 2013). This directly links to procedural justice, i.e. the fairness in decision-making that involves recognition, inclusion, representation and participation of the stakeholders (McDermott et al., 2013, Aragão et al., 2016). Therefore, selection of valuation methods should not solely be the researchers' decision.

5. Conclusion

We argue that integrated valuation should aim at representing all three value-dimensions (i.e. intrinsic, relational and instrumental), in order to represent the multiple stakeholders who depend on or have any interest in the issue at stake. Further, integrated valuation allows elicitation of opposing values, which are often at the basis of trade-offs and conflicts that might appear in a particular human-nature setting (e.g. Iniesta-Arandia et al., 2014; Turkelboom et al., *in press*). Integrated valuation therefore should be embedded in a process of stakeholder identification, characterization, involvement and engagement (see Reed et al., 2009; Mauser et al., 2013) in order to deal with trade-offs and to contribute to procedural justice.

6. Epilogue

Chapter 3 was peer reviewed for publication in Ecosystem Services and several improvements were made. Reviewers found the distinction between value types and dimensions unclear, and asked for more explicit description of method blind spots. In the final paper we clarified the distinction made between types and dimensions, and also discussed blind spots of the methods explicitely.

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Chapter 4 - Narrowing the gap between ecosystem service appraisal and governance support

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Chapter overview

This chapter focuses on how study purpose, information costs and stakeholder characteristics co-determine uptake and influence ecosystem service (ES) appraisals in governance. We discuss three complementary conceptual frameworks for understanding the integration challenges of ES appraisal methods – a rational actor view of the ES cascade, ES appraisal as value articulating institutions, and cumulative uncertainty in integrated valuation.   Based on the frameworks we formulate and test an information cost hypothesis to expain the relative frequency of different study purposes across broad classes of ES appraisal. We evaluate the hypothesis using survey data from a survey of OpenNESS case study coordinators and stakeholders in 26 case studies involving 80 ecosystem services appraisals. Our findings indicate mixed experiences with operationalisation of ES appraisals in decision-support. We find that the majority of appraisals conducted were for informative purposes, while significantly fewer had a decisive or technical policy design focus. We use the conceptual frameworks to discuss the operational challenges observed by case study stakeholders.   We recommend that future research on integrating plural values in ecosystem services appraisal place more emphasis on information cost when integrated valuation increases method complexity.

Chapter Keywords: integrated valuation, ecosystem service appraisal, ecosystem service governance, information costs, value articulating institutions

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1. Introduction

Ecosystem service (ES) appraisal methods include biophysical and socio-cultural assessments and monetary valuation. Recent reviews point to a persistent gap in the promise of ES appraisal methods to provide readily usable information for decision-support (Laureans et al. 2013; Ruckelhaus et al. 2015; Martinez-Harms et al. 2015). The challenge is broader than lacking operationalisation of monetary valuation in decision-making(TEEB, 2010b). Valuation in its broad sense of 'assigning importance' is inherently part of most decisions on natural resource and land use (Gómez-Baggethun *et al.*, 2014; Jacobs *et al.*, 2016). These literature reviews testify to a general pattern of 'disintegrated valuation', both in terms of integration of appraisals across the ES cascade (Haines-Young and Potschin, 2010), and operational gaps in application of ES appraisals in governance (Primmer *et al.*, 2015; Verburg *et al.*, 2016).

A broad research community is working to conceptualize the multiple values of nature and its benefits, beyond monetary valuation (IPBES, 2015). Efforts to mainstream the economics of nature (TEEB, 2010b) are being extended to operationalize plural values in decision-making. For example in a recent special issue[7], Jacobs et al. (2016) call for a 'new school of integrated valuation', which would include multiple values, in self-critical reflexive research, learning from real world applications and aiming at societal, rather than only academic impact. This 'new valuation school' calls for research that understands the socio-political setting of decision-making mechanisms and provides instrumental criteria of credibility and legitimacy that can help determine the appropriate level of integration. Of course, there are recent examples of integrated valuation across the ES cascade and across multiple types of value which are exceptions to the broad patterns revealed by literature reviews cited above, e.g. (Fontaine *et al.*, 2014; Martin-Lopez *et al.*, 2014; IPBES, 2015; van Oudenhoven *et al.*, 2015; Yee *et al.*, 2015; Barton *et al.*, 2016; Grêt-Regamey *et al.*, 2016). However, case study evaluations of how ES appraisals are operationalised in decision-making are limited.

Where are the operational gaps? Martinez-Harms *et al.* (2015) review 144 ES appraisals, and find that ecosystem service assessments do not capture the core steps of the decision making process, with much of the literature focused on quantifying and mapping the supply of ecosystem services. Another extensive review by Laurans *et al.* (2013) shows that a majority of studies have been conducted for informative uses, and only 2% of the 313 studies reviewed targeted decision-making. Among the reasons explaining the lack of valuation applications in policy, Laurens and colleagues suggest data inaccuracy, information costs, lack of expertise among decision-makers, and lack of compatibility between valuation methods and regulatory frameworks. Based on empirical case study experiences in the Natural Capital Project, Ruckelshaus *et al.* (2015) define four impact pathways for ES appraisal: (i) conducting research that is disseminated, (ii) making stakeholder differences transparent, and mediating through changing their perspectives, (iii) generating action in new policy and finance mechanisms, and (iv) producing outcomes for biodiversity, ecosystem services and well-being. While most studies in the Natural Capital project addressed the first three purposes to some degree, only one of 22 case studies had documented outcomes during the half a dozen years of the project. Ruckelshaus and colleagues argue that this is to be expected given the time needed to conduct studies

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[7] See special issue on Integrated valuation of ecosystem services: challenges and solutions Ecosystem Services, Volume 22, Part B, Pages 213-402 (December 2016) http://www.sciencedirect.com/science/journal/22120416/22/part/PB

and the significant time lags between multi-sector planning processes involved in ecosystem management and measurable impacts on the ground.

Chapters 1-3 in this report evaluate how the combination of a wide set of considerations affect method choice in ES appraisal.   This chapter focuses on how study purpose, information costs, and stakeholder characteristics co-determine uptake and influence in governance. We analyse a diverse set of real-world case studies of the OpenNESS project (Dick et al., in press), which have operationalised the concept of ecosystem services and applied a range of biophysical, socio-cultural and monetary ES appraisal methods, including 'hybrid' and 'integrated' valuation (Gómez-Baggethun *et al.*, 2014). Through this analysis, we report on the extent to which the project as a whole succeeded in narrowing the gap between ES appraisal and governance support – in other words how far OpenNESS came in putting the parentheses in '(dis)integrated valuation'.

The chapter is structured in six main sections. In section one we review recent studies that identify a gap between ecosystem services research and documentation of decision-support. We also review studies that explain the gap in terms of institutional characteristics of appraisal methods and different governance contexts.   In section two we present three complementary conceptual frameworks for explaining the challenges of ecosystem appraisal in decision-making. We use these frameworks to formulate an information cost hypothesis explaining the extent to which appraisal methods are expected to address 'explorative, 'informative', decisive' and 'technical design' study purposes. In sections three, we present the data from the case study leader and stakeholder surveys and our analytical approach. Section four analyses the results from researcher and stakeholder perceptions of 80 different applications of ES appraisal methods in OpenNESS case studies.   In Section five, we discuss the support for the information cost hypothesis and alternative explanations related to governance compatibility of methods.   In section six, we conclude with how our main findings address the research agenda proposed by the 'new school of integrated valuation' of ecosystem services.

2. Frameworks for understanding decision-support challenges of ES appraisal

2.1 Operational challenges of a rational actor model of ES appraisal

Typologies of ecosystem governance can help us understand the compatibility of ES appraisal methods with types of decisions that are relevant for different governance contexts (Laurans and Mermet, 2014; Primmer *et al.*, 2015).   These governance typologies can be seen in light of the ecosystem services cascade framework (Haines-Young and Potschin, 2010).   Here we elaborate on the ES cascade framework as a rational actor approach. The aim is to justify comparing all ES appraisal methods in OpenNESS – biophysical, socio-cultural and monetary - across a common classification of generic study purposes.   Laurans and Mermet (2014) propose a rational actor model as a kind of governance 'benchmark' for economists in how they perceive the decision-support role of ecosystem services valuation. In a *rational actor model* a single decision-maker makes choices based on calculating an optimal strategy among alternatives. Useful appraisal information in this model contains facts, data, clarified criteria and transparent calculation rules for values. Laurans and Mermet (2014) explain the operational gap in valuation studies in terms of a gap between the rational actor model economists think is operating, and the operational and policy models of governance operating in the real-world.
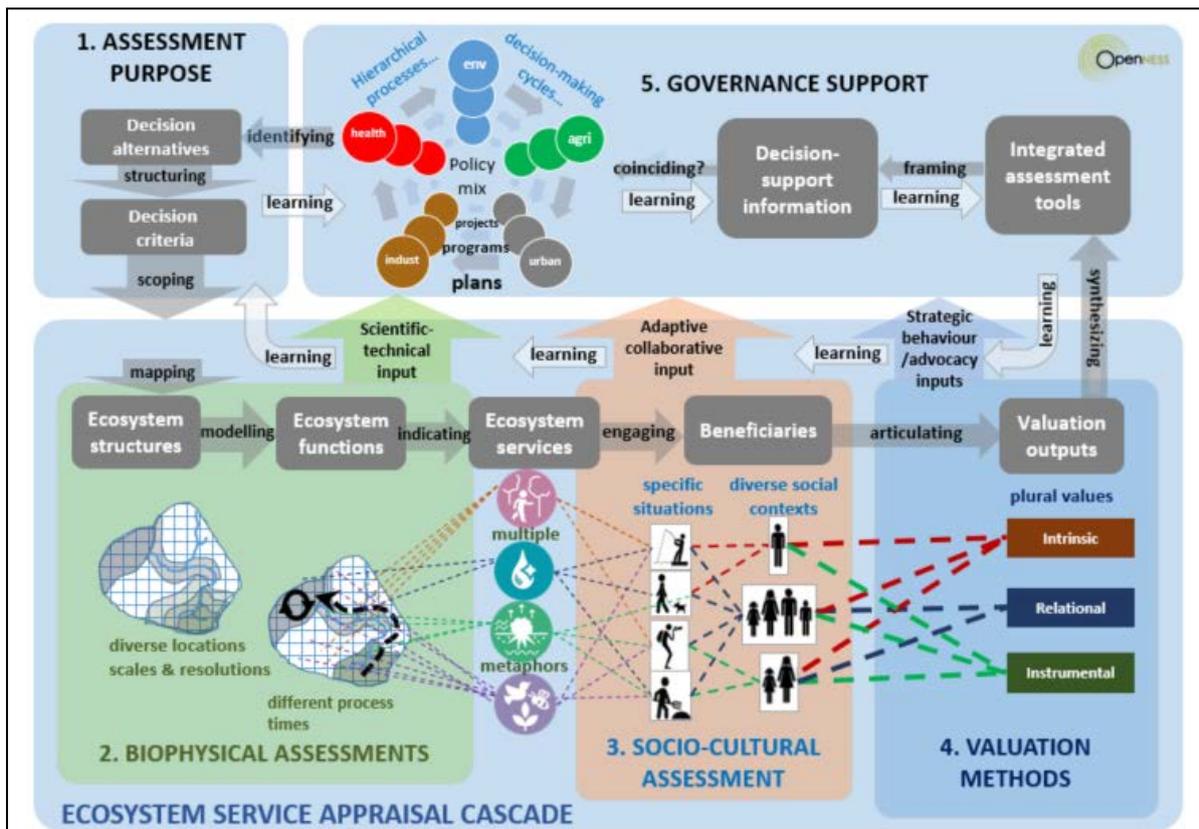
Figure 4.1. A rational actor approach to integrated appraisal across the ecosystem service cascade

Sources: ecosystem service icons by Oslo Urban Environmental Agency. People icons from Shutterstock.

The ecosystem service cascade framework is a rational actor approach, suggesting a defined set of decision alternatives and cascade of ecosystem assessments leading to integrated assessment and synthesis for clearly identified decision-makers. In an idealised rational actor model, integrated assessments synthesize information across methods, are integrated within governance processes, and encourage iterative learning across disciplines and between science and policy. In this rational conceptual model, biophysical and socio-cultural assessments do not provide values - inputs to decision-making are handled by valuation methods which are dedicated to articulating values (sensu Vatn 2005) for each decision criteria. The operationalisation of this rational approach is challenged by the time and resources required for an integrated assessment to support decision-making, relative to the different speeds of sector decision-making cycles at different hierarchical levels. Interated assessment faces the challenge of identifying and coinciding with decision-making moments of opportunity. Instead, individual methods provide faster, partial inputs to spesific types of governance (sensu Primmer et al. 2015). Mapping and biophysical modelling provide input to scientific-technical governance, socio-cultural assessments support adaptive collaborative governance, and valuation outputs are used individually in governance of strategic behaviour, such as for advocacy. Each type of assessment, when used in support of governance, is emphasising the importance of particular structures, functions, and beneficiaries, and as such is articulating value (sensu Gómez-Baggethun *et al.*, 2014; Martín-López *et al.*, 2014). Assessments are conducted individually and are examples of 'disintegrated valuation'. Hierarchical governance (sensu Primmer et al. 2015) has a mandate to integrate. Integration of information to support decisions represents power. It is a power that government will in many cases reserves for itself, in which case research will have a mandate only to 'explore' and 'inform' (rather than 'decide' and 'design').

However, as the notions of value articulation (Vatn, 2005; Stagl, 2012) demonstrate, a rational actor model extends beyond economists and economic valuation methods. While the ES cascade framework (Haines-Young and Potschin, 2010) is a conceptual framework used to understand ecosystem services metaphorically, it also suggests a sequential cascade of linked ecosystem assessments, leading to final valuation end-points that are the basis for decision-making (Braat *et al.*, 2014; Barton *et al.*, 2016). This rational actor understanding of the ES cascade has been challenged (Dick *et al.*, 2016) and the framework has been further developed (Primmer *et al.*, 2015; Potschin and Haines-Young, 2016). For example, iteration and learning across appraisal methods in practice mean that integrated appraisal is not linear. However, we argue that a rational actor model for ES appraisal illustrated by the ES cascade continues to guide study design in a number of research projects.

In the rational actor model, valuation end-points are the basis for decision-making. In a sequential model chain represented by the ES cascade, it may at first sight seem wrong to hold biophysical mapping and modelling methods to the same standards of operational decision-support as dedicated valuation methods. However, there is comparability (TEEB, 2010a). 'Value' in its widest sense reflects ' importance' pathways (IPBES, 2015). Importance pathways do not only go through the ES cascade end-points of value (Gómez-Baggethun *et al.*, 2014). Primmer et al. (2015) discuss how different types of governance require different scientific-technical, adaptive-collaborative and strategic information inputs. Primmer et al. (2015) explain how different appraisal methods provide information to serve different types of governance, with assessment methods acting as value articulating institutions along the ES cascade. In Figure 4.1 we label these various types of input collectively as 'governance support' (as distinct from direct decision support). These inputs serve as arguments for importance (value) in organizational and policy modes of decision-making, which are alternatives to the rational actor model which focuses on valuation end-points(Laurena and Mermet 2014). The long time required to carry out integrated assessments of policy alternatives also means that appraisal processes will struggle to coincide with decision-support opportunities and needs (Barton *et al.*, 2016). The integrated approach required by the rational actor model of decision-making is in practice 'short circuited' by individual methods providing more timely information to address more immediate knowledge gaps. Individual methods provide 'disintegrated valuation' inputs that nevertheless support governance, but not necessarily in the sense of direct assessment of decision alternatives as envisaged in a rational decision-making model. In summary, Figure 4.1 serves as a rational actor 'benchmark' for integrated ES appraisal. It suggests that ES appraisal methods are comparable as value articulating institutions, and that the integration of these methods faces common challenges of cumulative uncertainty and information costs, issues we turn to in the next sections.

2.2 ES appraisal methods as value articulating institutions

It is increasingly recognised that choices by individuals and valuation of those choices, are context-dependent. Values and preferences are conditioned by individuals' capabilities in relation to the specific biophysical and social contexts, and articulated in ways that reflect the individuals' roles and the norms they adhere to in their social contexts (Vatn, 2005a). The institutional differences in the articulation of ecosystem services values in monetary and socio-cultural valuation has been discussed by a number of authors, e.g. in stated preference valuation methods, benefit-cost analysis and multi-criteria decision analysis (Vatn, 2005b, 2009; Stagl, 2012; Klain *et al.*, 2014; Martín-López *et al.*, 2014; Saarikoski *et al.*, 2016). Vatn (2009) argues that deliberative ES appraisal methods more generally

can be understood as different value articulating 'institutions'[8] (Jacobs, 1997). Primmer et al. (2015) argue that the ecosystem service concept itself, when embedded in governance, acts as a value articulating institution.

The framing of ES appraisal methods in general – not only valuation methods – as value articulating institutions calls for comparative analysis regarding operationalisation across methods types that are not normally compared (Vatn 2009). Figure 4.2 provides examples of indicators of importance in the context of ES appraisal methods across the ES cascade, using the example of cultural ecosystem services. The theory of value articulating institutions and governance of ecosystem services deconstructs the rational actor model in Figure 4.1. It opens the way for comparing all ES appraisal methods using the same factors to explain governance compatibility and operational constraints. At the same time, understanding all ES appraisal methods as value articulating institutions presents a challenge for operationalisation. If ES values and the valuation process are understood as highly contingent on the decision-making context, it has to be accepted that values are less objective, generalisable and transferable. There is tension between researchers' sense of their role as providers of objective information and the contingent characteristics of values (Laurans and Mermet, 2014). Figure 4.2 illustrates the arguement that this contingent characteristic extends to all ES appraisal methods when used directly for decision-support.

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[8] 'Institutions are the conventions, norms and and formally sanctioned rules of a society. They provide expectaions, stability and meaning essntial to human existence and coordination. Institutions support certain values, and produce and protect specific interests.' Vatn 2016, p.78
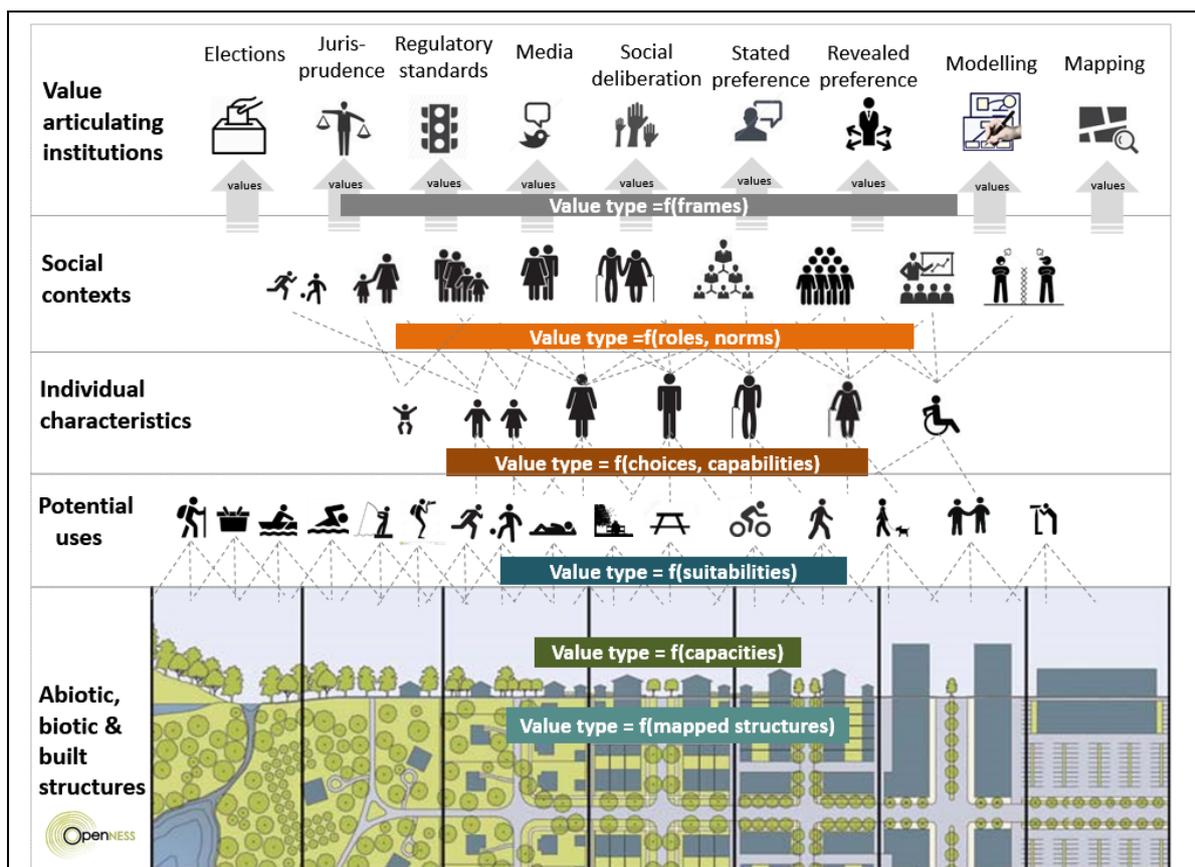
Figure 4.2. Ecosystem service appraisal methods as value articulating institutions

Source: own elaboration. People icons by Shutterstock, Freestock, landscape gradient by Duany Plater-Zyberk & Company.

Ecosystem structures are mapped, biophysical capacities are modelled, capabilities and choices are assessed using socio-cultural and economic valuation methods. Socio-cultural methods appraise norms and rules. The idea of value articulating institutions can be extended to all the ecosystem appraisal methods - including biophysical methods - to the extent that they express relative importance of structures or functions.

2.3 ES appraisal methods and uncertainty

Literature reviews highlight the cost of information as one of several challenges to operationalisation of ecosystem services (Bagstad *et al.*, 2013; Laurans *et al.*, 2013; Ruckelshaus *et al.*, 2015). Bagstad *et al.* (2013) argue that information cost of studies (time and resources to obtain data, analyse and communicate results) is one of the most important challenges, while being somewhat neglected by ecosystems services research. While not the object of ES appraisal research per se, information costs are key considerations of ES appraisal practitioners (see Dick et al. in press, Chapter 1 and Harrison et al. in press, Chapter 2 and Dunford et al. in press). Integrated ES appraisal for decision-support faces a challenge of cumulative uncertainty from biophysical and socio-cultural heterogeneity, and value plurality (Gómez-Baggethun *et al.*, 2014). Cumulative uncertainty in integrated ES appraisal is the focus of our third conceptual framework (Figure 4.3).
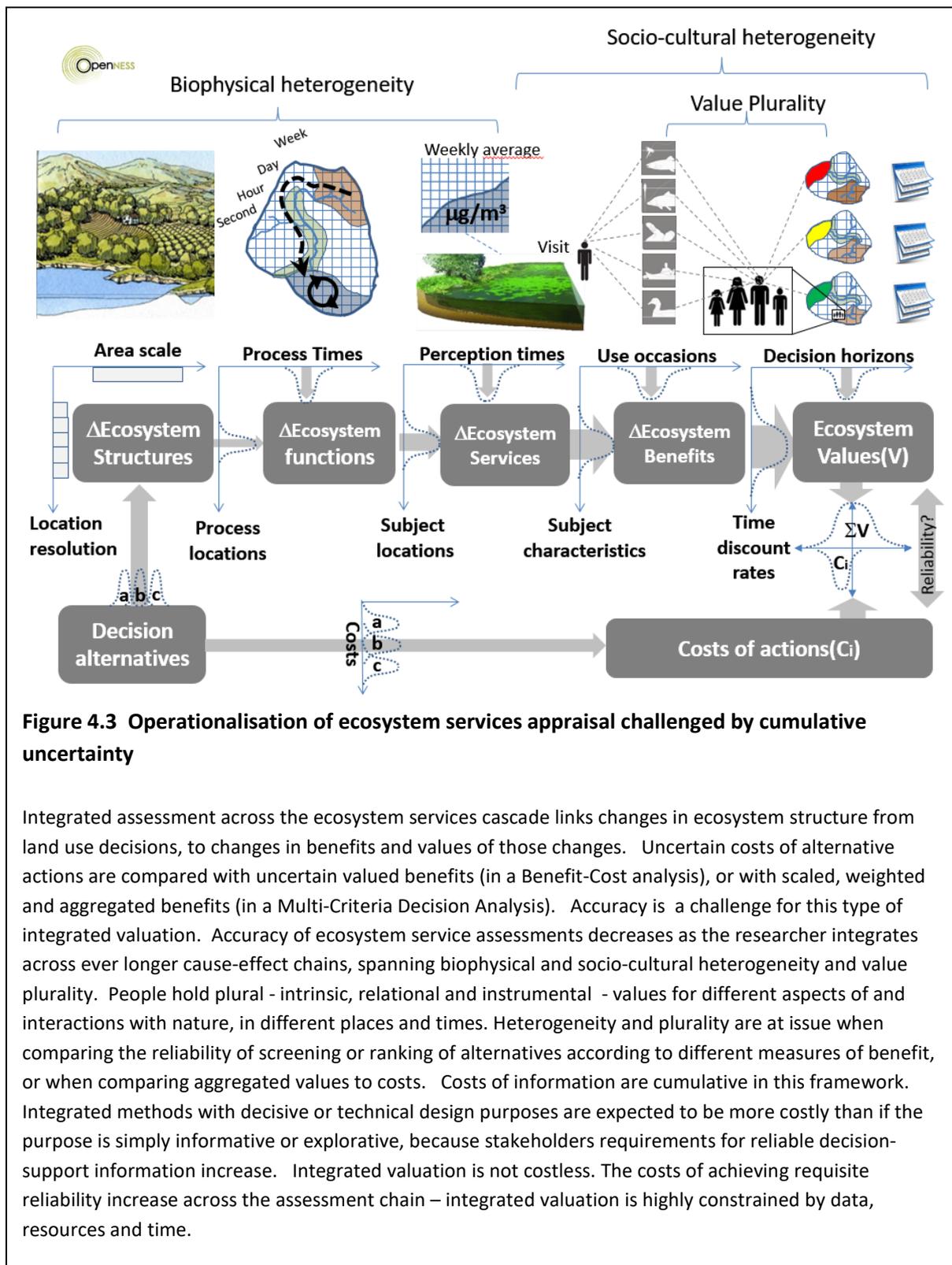
Figure 4.3 Operationalisation of ecosystem services appraisal challenged by cumulative uncertainty

Integrated assessment across the ecosystem services cascade links changes in ecosystem structure from land use decisions, to changes in benefits and values of those changes. Uncertain costs of alternative actions are compared with uncertain valued benefits (in a Benefit-Cost analysis), or with scaled, weighted and aggregated benefits (in a Multi-Criteria Decision Analysis). Accuracy is a challenge for this type of integrated valuation. Accuracy of ecosystem service assessments decreases as the researcher integrates across ever longer cause-effect chains, spanning biophysical and socio-cultural heterogeneity and value plurality. People hold plural - intrinsic, relational and instrumental - values for different aspects of and interactions with nature, in different places and times. Heterogeneity and plurality are at issue when comparing the reliability of screening or ranking of alternatives according to different measures of benefit, or when comparing aggregated values to costs. Costs of information are cumulative in this framework. Integrated methods with decisive or technical design purposes are expected to be more costly than if the purpose is simply informative or explorative, because stakeholders requirements for reliable decision-support information increase. Integrated valuation is not costless. The costs of achieving requisite reliability increase across the assessment chain – integrated valuation is highly constrained by data, resources and time.

Hierarchical governance has to integrate information from across the ecosystem services cascade (Primmer et al. 2015). Systems analysis tells us that methodological and measurement error across conditionally dependent knowledge domains is cumulative (Barton et al. 2016). So errors in appraisal methods can be expected to accumulate when aggregated in sequence across a cascade of models for decision-support. How can we evaluate methods' information costs and the implications for

governance? If cumulative uncertainty is a feature of ES appraisal, then valuation for 'decisive' or 'technical design' of decision alternatives is a more challenging type of appraisal in terms of reliability requirements, than 'identifying' or 'demonstrating' value. Cumulative uncertainty is an important reason we expect to find few valuation studies providing decision-support in the review literature (Laurans *et al.*, 2013; Martinez-Harms *et al.*, 2015). Also, cumulative uncertainty as illustrated in Figure 4.3 leads us to expect individual biophysical appraisal methods to be used more frequently for decision-support than valuation methods employed as end-points in a cost-benefit analysis.

2.4 Information cost hypothesis

The TEEB (2010b) study defined valuation purposes as 'identifying', 'demonstrating' and finally 'capturing' value, imply an ordering which can be explained by increasing costs of information. A tiered approach to ecosystem service appraisal is often recommended (Tallis and Polasky, 2011) because methods with higher spatial and temporal resolution have increasing data demands. Gómez-Baggethun and Barton (2013) identify a range of purposes of urban ecosystem service valuation, including (i) awareness-raising, (ii) accounting, (iii) priority-setting, (iv) instrument design, and (v) damage compensation litigation. They argue that different purposes can be organised along a gradient of increasing requirements in data accuracy and reliability from decision-makers, and hence in information costs. Schröter *et al.* (2014) proposed a similar ordering of study purposes in the context of ecosystem service accounting at regional and national scales.Here we combine the typologies of decision contexts reviewed above (Gómez-Baggethun and Barton, 2013; Laurans *et al.*, 2013; Martinez-Harms *et al.*, 2015; Ruckelshaus *et al.*, 2015) into *explorative, informative, decisive* and *technical design* purposes of ecosystem service assessments (Figure 4.4).
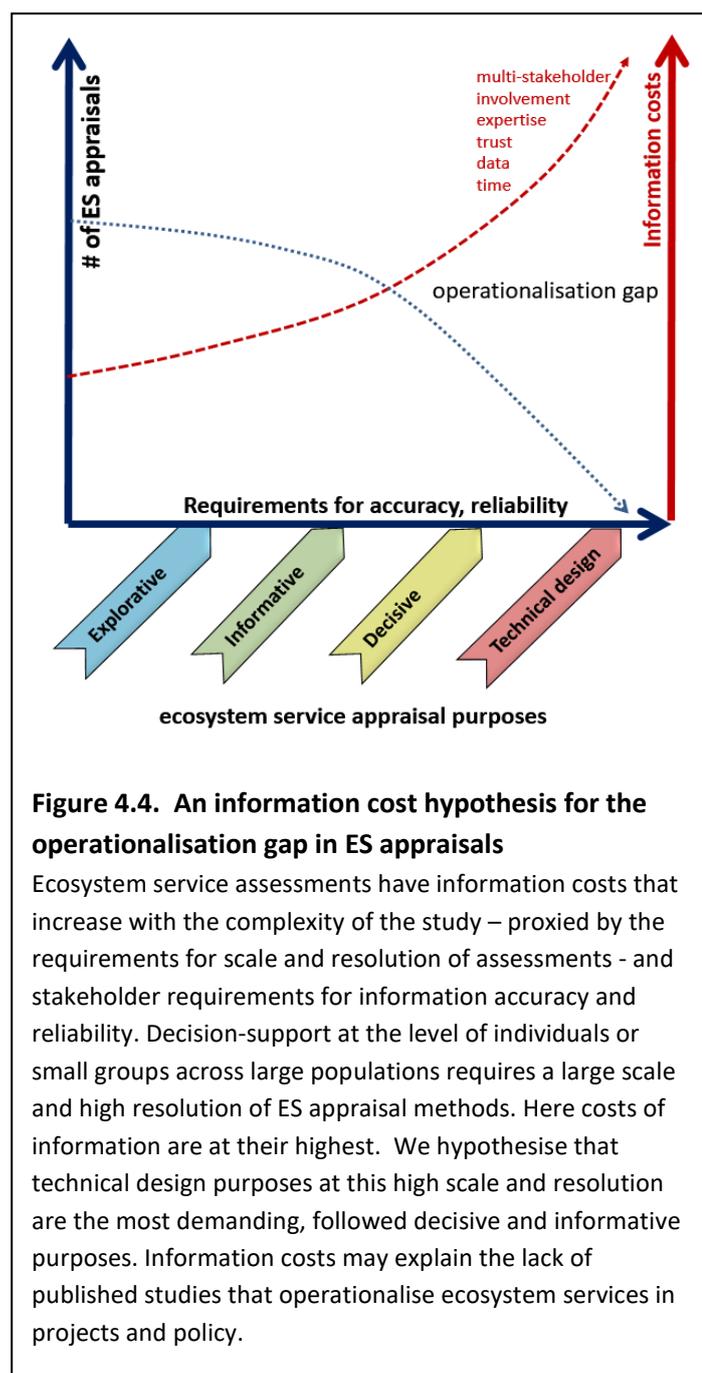
Figure 4.4. An information cost hypothesis for the operationalisation gap in ES appraisals

Ecosystem service assessments have information costs that increase with the complexity of the study – proxied by the requirements for scale and resolution of assessments - and stakeholder requirements for information accuracy and reliability. Decision-support at the level of individuals or small groups across large populations requires a large scale and high resolution of ES appraisal methods. Here costs of information are at their highest. We hypothesise that technical design purposes at this high scale and resolution are the most demanding, followed decisive and informative purposes. Information costs may explain the lack of published studies that operationalise ecosystem services in projects and policy.

We suggest that information costs vary systematically across these four broad study purposes and may explain a significant part the 'operationalisation gap' of ecosystem services concept in policy decision-support and design. Based on a theory of cumulative uncertainty in integrated appraisal (Figure 4.3), we can formulate the hypothesis that *technical design* purposes have the highest information costs, followed by *decisive* and *informative* purposes. Finally, *explorative purposes* rely on processes of trial and error, and consist of the impact pathway of conducting and disseminating research (Ruckelshaus *et al.*, 2015). We hypothesise that *explorative purposes* imply the lowest information costs. They are also likely to be the most common in published academic literature. Constraints on data, budget and time available are expected to be important reasons for method selection according to this information cost hypothesis. To the extent that our information cost hypothesis does not find support in our case study data, we will discuss alternative explanations identified in the review literature, such as lack of expertise among decision-makers, and lack of compatibility between appraisal methods and governance types.

3. Materials and methods

The OpenNESS project was designed to operationalise the ecosystem services concept in 27 case studies, through close collaboration between researchers and stakeholders (Dick et al. in press). In the last year of the project, 26 case study leaders and over 246 stakeholders responded to targeted surveys evaluating the different methods applied during the project period from 2013 to 2016.

3.1 Case study leader survey

A survey was circulated to case study research teams in 2016, in which the case study leaders were asked to identify all the appraisal methods used within their case study. For each appraisal method, the respondents were asked to score considerations that influenced their decision to use that method within their case study. For the complete survey protocol, see Dick et al. (in press) Supplementary Material – "Annex 4 Case study context reporting forms part 2". See also Dunford et al. (in press) for an analysis of a comprehensive evaluation of case study considerations. In this chapter we focus on the subset of considerations concerning study purposes and information constraints. Table 4.1 describes 18 different study purposes in ecosystem services assessment, based on a synthesis of decision contexts and impact pathways in the literature (Gómez-Baggethun and Barton, 2013; Laurans *et al.*, 2013; Martinez-Harms *et al.*, 2015; Ruckelshaus *et al.*, 2015) and adapted to the OpenNESS 26 case studies included in this chapter.

Table 4.1 Range of study purposes of each ecosystem service appraisal method scored by case study representatives

Explorative	Conduct research aimed at developing science and changing understanding of research peers
E1	Theory and concept development
E2	Hypothesis formulation and testing
E3	Method development and testing
Informative	Change perspectives of public & stakeholders
I1	Assessment of current state
I2	Assessment of long-term historic trends
I3	Assessment of potential future conditions
I4	Evaluation of existing projects and policies
I5	Raising awareness of the importance of ES
I6	Raising awareness of trade-offs and conflicts between ES
Decisive	Generate action in specific decision problems by stakeholders
D1	Decision problem formulation and structuring
D2	Criteria for screening alternatives
D3	Criteria for ranking alternatives
D4	Criteria for spatial targeting (zoning & planning of alternatives)
D5	Arguments for negotiation, shared norms & conflict resolution
Technical design	Produce outcomes through design and implementation of policy instruments with stakeholders
T1	Standards & policy target-setting
T2	Land and natural resource management rules & regulations
T3	Licencing / permitting / certification
T4	Pricing, setting incentive levels
T5	Establishing levels of damage compensation

Note: P=18 case study purposes

For our analysis method purposes were classified into broad categories including explorative, informative, decisive and technical design in order to test the information cost hypothesis in Figure 4.4. A total of 80 ES appraisals in the OpenNESS project were ordered into 5 classes following the ES appraisal cascade discussed in Figure 1 (Table 4.2). Method descriptions are provided in Harrison et al. (in press). Most case studies applied more than one method. The survey evaluated case studies' reasons for selecting methods across a large number of criteria, including researchers own expertise, available time and resources, local conditions and needs expressed by stakeholder advisory boards (Dunford et al. in press). Integrated mapping-modelling methods and decision-support methods were grouped together in a single class of "synthesising" methods.

Table 4.2. Classification of ecosystem service appraisal methods used by case studies

Mapping (n=24)	Biophysical Modelling (n=10)	Monetary valuation (n=12)	Socio-cultural valuation (n=25)	Synthetising methods (n=9)
• ESTIMAP • Matrix approach • Quickscan • Smarthphone Apps • PPGIS	• SITE Landuse model • Bayesian belief network • Climate envelope modelling • Hydrological model • Meta-analysis	• Time use value • Value transfer • Cost-based • Revealed preference • Stated preference	• Questionnaire & narrative analysis • Photoseries analysis • Preference assessment • Time use • Q-method • Deliberative valuation • Stakeholder analysis • ES cascade focus group	• Integrated mapping-modelling (INVEST, EcoServ) • Scenario development • Multi-criteria decision analysis • Benefit-cost analysis

Note: C=5 method classes. N=80 individual method applications; n_c=method applications per class. See Supplementary Material S1 and Harrison et al. in press for method descriptions.

For each method 26 case study leaders were asked 'To what extent is the way that you use the method in your case study described by the purposes listed (in Table 4.1)'? (scores: 0 = "not relevance"; 1 = "relevant" 2 = "primary purpose"). All methods were scored for all 18 purposes, considering that a single method can have multiple purposes. Regarding considerations for methods selection case study leaders were asked 'To what extent are the following practical/research-related considerations factors that influenced your choice of this method?' (scores: 0 = "not at all"; 1 = "to some extent" 2 = "very much"). From this battery of questions we use answers regarding data, budget and time constraints as proxy indicators for information cost[9].

3.2 Case study stakeholder survey

After three years of OpenNESS case study work in close consultation with advisory boards (CAB), a standard questionnaire was administered to 246 case study stakeholders in 2016. For the complete survey protocol, see Dick et al. (in press) with Supplementary Material – "Annex 1 Practitioner's perspective questionnaire".   Three methods were used for selecting respondents: (i) restricting the respondents to CAB members (8 case studies), (ii) complementing the CAB respondent group with stakeholders outside the CAB (8 case studies), and (iii) including all stakeholders with relevant involvement in the process, as evaluated by the CAB and case study leader (11 case studies).   Given the flexibility and variation across case studies in stakeholder participation during the three years of case study, the importance of CAB membership was assessed in relative terms. For the OpenNESS project as a whole stakeholders self-reported their 'membership of the CAB' as follows: *very applicable* (39%), *applicable* (14%), *somewhat applicable* (3%), *little bit applicable* (6%) and *not applicable* (38%).

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[9] We also applied a survey to case study leaders to quantify personmonths and expenses allocated per appraisal method.   Application of multiple methods per case study meant that several case studies were unable to assign costs exactly. Due to missing responses we reverted to use of the qualitative question described above which was responded to by all but one case study.

Partial involvement in the CAB reflects the dynamic nature of CAB membership, with individuals leaving and new members joining during the lifetime of the project in some case studies (see Dick et al. in press).

The stakeholder questionnaire was structured into four main topics (i) self-characterisation of stakeholders, (ii) perception of the participatory process followed in the case study, (iii) perceived impact, and (iv) practical usefulness of tool(s) and allowed the stakeholders to feed back their experiences anonymously. We use a selection of the stakeholder survey data for our analysis, in particular, the stakeholders' degree of participation in the case study advisory board, the extent to which they partipated in study design, method selection, knowledge co-production and were informed about results. Knowledge co-production was defined as 'attending workshops/meetings/ and stakeholder engagement activities' (question wording provided in Supplementary Material S2).

3.3 Testing the information cost hypothesis

We defined a t-test for differences in the mean relevance scores of method classes between adjacent types of study purpose (ordered by expected information costs). Using the scores assigned by case study leaders for each method tested in their case studies, we calculated the mean scores (s) of each method class (c) over each class of study purpose (p) (as defined in Table 4.2 and Table 4.1, respectively).

Based on the 'information cost' hypothesis illustrated in Figure 4.4 we formulate a two-sided t-test. Given that we are testing whether there is a consecutive ordering of methods over pairwise purposes we use the reported confidence levels of one side of the t-test,

$Pr(T < t)$, Ho: mean(diff) = 0 , Ha: mean(diff) < 0 ,

where mean(diff) is the difference in mean scores between pairwise consecutive study purpose categories, organised in order of increasing information costs, as defined in Table 4.1 (Explorative – Informative, Informative – Decisive, Decisive – Technical design, Informative – Technical Design). In other words, the expectation with our information cost hypothesis is that

mean(E-I)<0, mean(I-D)<0, mean(D-T)<0, and mean(I-T)<0,

so that if for example mean(I-D)<0 is true, we are confident that the mean score of *informative* method applications is higher than the mean score of *decisive* method applications. Table 4.3 reports the 90% confidence levels $Pr(T < t)$. Some method classes have relatively few observations (modelling, monetary valuation, and synthesising methods). For these method classes the power of the t-test is lower, and the test is less likely to observe the hypothesised difference in means between purposes.

We contrasted the results of the hypothesis tests with case study leaders' self-reported evaluation of importance of data, time and budget constraints in selecting the methods actually used (versus an alternative method not used). Results are reported in Figure 4.6. Recalling Laurans *et al.* (2013), we also evaluate complementary explanations to the information cost hypothesis using data from the stakeholder survey; stakeholders' self-reported roles in the project, their degree of participation in decision-making, their perceptions of the general impact of the appraisal methods on decision-

making, and prior researcher-stakeholder collaboration experience. We use a twoway fractional polynomial plot in STATA to illustrate (i) whether stakeholders' participation in case study advisory board is correlated with co-design of ES appraisal methods, and (ii) whether the length of time researchers had worked with stakeholders in the case study prior to OpenNESS is correlated with the importance scores for different study purposes.

4. Results

4.1 Uses of methods for different purposes

Figure 4.5 shows the mean relevance scores for each of the 5 method classes (defined in Table 4.2) and for each of the four groups of study purposes (defined in Table 4.1). Our hypothesis has some support in the case study leader survey data - the applicability of appraisal methods is negatively correlated with an ordering of study purposes by increasing information costs from *informative* to *decisive* to *technical design* (Figure 4.5). The notable exception is *synthesizing* methods which scored the highest relevance for *decisive* purposes.

The detailed distributions of relevance scores are given in Figure SM4.1, Supplementary material. Comparing methods for the same purpose, we see that 'mapping' methods scored almost as highly as 'synthesising' methods for *decisive* purposes. Broadly speaking, mapping scored more highly than other individual methods across all purposes. Monetary methods scored the lowest across all purposes (Figure SM4.1).

A closer inspection of the distributions using the t-test shows that most of the adjacent purposes are different by order of increasing study costs (Table 4.3). There are some exceptions. For example, in the case of mapping methods we are only 83% confident that *decisive* purpose is more prevalent than *technical design*; for socio-cultural methods we are only 79% confident that *informative* purposes are more prevalent than *decisive* purposes. However,on the whole Table 4.3 shows that we can have confidence in our information cost hypothesis regarding the individual appraisal methods. For 'synthesising' methods the converse is true. They are most prevalent for *decisive* purposes, but not for *technical design*.

The mean scores by purpose class in Figure 4.5 hide a lot of heterogeneity within each class. Figure SM4.1 in Supplementary materials provides further detail across the 18 different detailed study purposes. From this more detailed picture we see that among *explorative* study purposes *methods development & design* was the most important study purpose for case studies. Among *informative* purposes, creating awareness of the current state and importance of ecosystem services were the dominant purposes across the different case studies. *Decisive* purposes had no dominant detailed purpose. Decision-support tools (MCDA, BCA) and integrated mapping-modelling methods were on the whole more relevant for *decisive* purposes than were mapping, modelling and valuation methods on their own. For *technical design* purposes, input to design of natural resource *management rules and regulations* was the most relevant technical design purpose across OpenNESS case studies, scoring as high as decisive purposes for both mapping methods and synthesis methods.
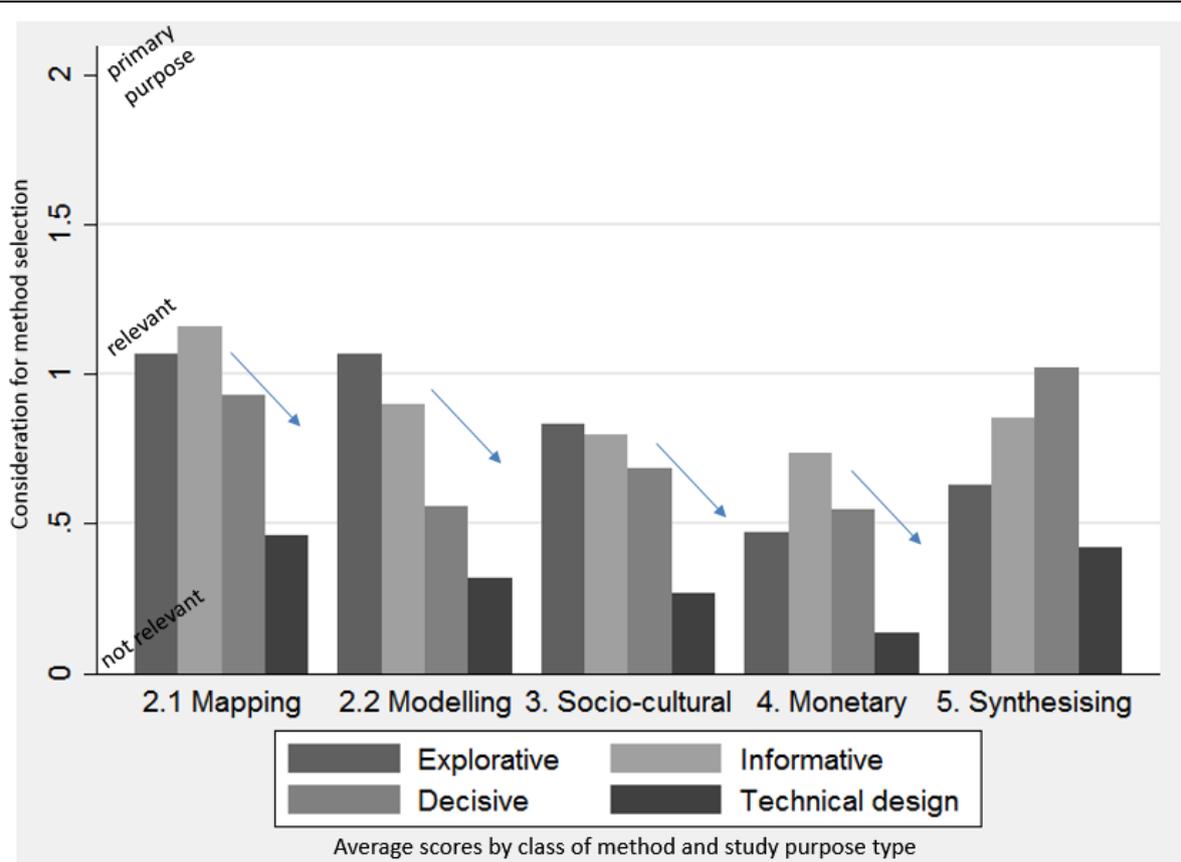
Figure 4.5 Ecosystem service assessment and valuation methods are ordered by purpose broadly in line with the information cost hypothesis. The figure shows mean relevance scores of the purposes of 80 methods from 26 case study leader respondents.

Table 4.3 The ordering of methods according to the information cost hypothesis is significant for most of the consecutive study purposes.

	Pr(T < t) for Ho: mean(diff) = 0 , Ha: mean(diff) < 0			
Purposes: **Method groups:**	**Explorative-Informatve** mean(E-I)	**Informative-Decisive** mean(I-D)	**Decisive-Technical Design** mean(D-T)	**Informative-Technical design** mean (I-T)
Mapping	t = -0.9725 Pr= 0.1678	t = 2.3522 Pr= 0.9886	t = 4.0675 Pr= 0.9999	t = 7.6059 Pr= 1.0000
Modelling	t = 1.1971 Pr= 0.8766	t = 1.4362 Pr= 0.9159	t = 0.9909 Pr= 0.8326	t = 3.8562 Pr= 0.9994
Socio-cultural	t = 0.2905 Pr= 0.6136	t = 0.8008 Pr= 0.7863	t = 2.5861 Pr= 0.9935	t = 4.5755 Pr= 1.0000
Monetary	t = -1.6848 Pr= 0.0531	t = 1.3250 Pr= 0.9006	t = 3.3544 Pr= 0.9986	t = 6.1671 Pr= 1.0000
Synthesis	t = -0.9104 Pr= 0.1881	t = -0.6888 Pr= 0.2504	t = 2.6572 Pr= 0.9914	t = 2.0364 Pr= 0.9707

Note: T-test of the difference in the mean of method relevance scores between consecutive study purposes

Figure 4.6 illustrates the relative importance – as assessed by case study leaders - of data, time and budget constraints in the selection of methods used in the case studies, compared to alternative methods. Data constraints are more important in relative terms to time and budget constraints for 'modelling' and to some extent for 'monetary valuation'. But more striking is the fact that the mean importance of data, time and budget constraints in method selection is low, varying from 'to some extent' to 'definitely not'. In other words, none of these constraints – as judged by case study leaders – were 'definitely' important in selecting the methods they used in case studies. We also looked at whether stakeholder-researcher familiarity increased the likelihood of decisive and technical design purposes of studies, using as a proxy the number of years they had worked with stakeholders before initiating OpenNESS. There was no visible effect for any of the study purposes (the results are shown in


Figure 4.6 **The importance of constraints** in choice of methods relative to their alternatives reported by case study leaders respondents (n=27).

Supplementary Material, Figure SM4.2).   In section 5.1 we discuss the implications of these results for how we interpret these patterns regarding the information cost hypothesis.

4.2 Participation in appraisal method selection

Slightly fewer than half of the stakeholders interviewed "make decisions" about the ecosystem services investigated, while over half "contribute to decision-making"; the majority of stakeholders were "affected" by or "interested" in the ecosystem services issues assessed in the case studies (Figure SM4.3).   A majority of stakeholders found that appraisal methods lead to a "change in future vision in the area", "change in the way information and tools are used to support decisions", "change in decision-making" and "change in actions" (Figure SM4.4).   These broad characteristics of the stakeholders reported in Supplementary Material testify to OpenNESS providing governance support in different ways across the 'ES appraisal cascade' (Figure 4.1). The stakeholder survey shows that the type and degree of governance support depends on the level of interaction with researchers in the case study advisory board. Figure 4.7 shows that stakeholders' advisory role is weakly correlated with some, but not all, types of science-policy interaction.

Across the types of stakeholder participation in case study advisory boards, the level of participation in 'study design' is a 'little bit applicable', increasing to 'somewhat applicable' for the most active CAB members (Figure 4.7, upper left hand panel). Stakeholders participated a 'little bit' in method selection, and it was not significantly different for higher levels of CAB involvement (Fig.7, upper right hand panel).   Looking at knowledge co-production and information about project results, the picture looks quite different. Knowledge co-production increased significantly to 'applicable' for stakeholders who percieved themselves fully as members of the CAB (Fig. 7, lower left panel). All stakeholders were

informed of project results ('applicable'), with the level of information being significantly higher for the most active CAB members ('very applicable').
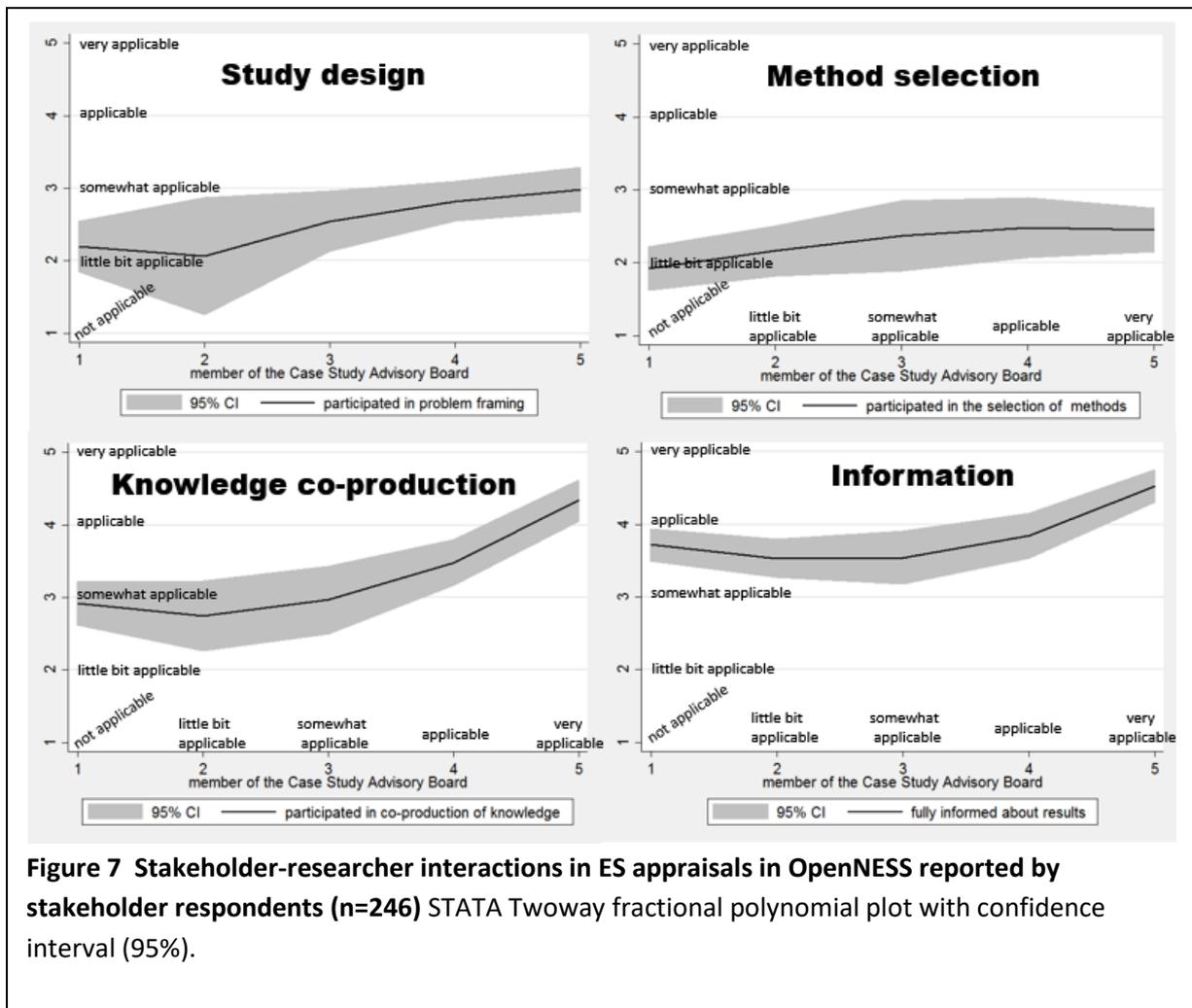
Figure 7 Stakeholder-researcher interactions in ES appraisals in OpenNESS reported by stakeholder respondents (n=246) STATA Twoway fractional polynomial plot with confidence interval (95%).

5. Discussion

5.1 Uses of methods for different purposes

To explore the reasons behind the choice of different appraisal methods and their purposes, we formulated an information cost hypothesis (Figures 4.3-4.4). The hypothesis is supported by the data from OpenNESS case studies, with some exceptions. In particular the difference between *decisive* and *technical design* purposes, and to a lesser extent the difference between *informative* and *decisive* purposes are apparent. Individual methods for *informative* purposes from different parts of the ES appraisal cascade were predominant, while *synthesising* methods that focus on valuation end-points are less frequent.

Looking more closely at the constraints underlying the information cost hypothesis, we find an initially surprising result. Contrary to the expectation that limited use of appraisals for *decisive* and *technical*

design purposes is due to constraints on information (either from lack of data, budget constraints relative to information cost, or time available relative to problem complexity), we find that on average data, time and budget constraints were not perceived as strong constraints (Figure 4.6).   The lack of importance of these factors could be due to *informative* purposes being more important than *decisive* and *technical design* purposes.   An additional explanation may be that as a research project, methods were relatively well resourced, compared to what they would be in e.g. a consultancy. Also, in several case studies that had longer term engagements with their case study sites there were opportunities to combine several financing sources, as well as having access to established data bases at long term socio-ecological research sites.   Regarding whether stakeholder-researcher familiarity increased the likelihood of more challenging and costly purposes of ES appraisal, we find no clear correlation between the importance of *decisive* or *technical design* study purposes, and the number of years researchers have worked with stakeholders before the OpenNESS case study started (Figure SM4.2).

5.2 Co-design of purpose and method selection by stakeholders

The stakeholder survey results complemented that of the case study leader survey above. The OpenNESS project has been operational in the sense of having active participation of stakeholders who are also decision-makers. We looked closer at the type of engagement and the way in which stakeholders interacted with the project. About half the stakeholders did not participate in the problem framing of the project, and slightly more than half did not participate in selecting the assessment methods (summing 'not applicable' and 'slightly applicable' responses). In terms of our framework (Figure 4.1), stakeholder participation in scoping (study design) and selection of methods was generally low (Figure 4.7). On average the OpenNESS case studies did better in the co-production of knowledge, and in providing information inputs to case study advisory boards (governance support rather than explicit decision support, Figure 4.1).

Despite case study leaders' perception that "synthesis" methods played a decision-support role, there are indications from the stakeholder survey that the decision-making role of these methods was potential, rather than actual (Figure SM4.3, SM4.4). As also reported in Dick et al. (in press), only a bit more than 20% of stakeholders thought that OpenNESS assessment methods had already resulted in "a change in decision making" in the case study site. A further 40% thought that such a change was likely to take place, while the remaining did not assume such influence. The divergence between researchers' and stakeholders' perceptions of the decision making role of appraisal methods can partly be traced back to the engagement processes that took place in the case studies. It highlights that involving the 'right' stakeholders (in terms of having decision making power) is crucial to realize real governance outcomes.   Still, our assessment is somewhat more optimistic than findings from the Natural Capital project (Ruckelshaus et al., 2015) where a 3-4 year research project was deemed insufficient to observe operational changes in decision-making.

The question remains whether the expectation of change in decision-making procedure can be interpreted as an actual sign of operationalisation. Based on stakeholder survey results the OpenNESS project was relatively successful in achieving decision-maker participation in the case study advisory boards (Figure SM4.3).   However, on the whole case studies were less effective in engaging them in study design and methods selection than in knowledge co-production and keeping them informed (Figure 4.7).   Laurans and Mermet (2014) point out that studies for informative purposes can have a

decisive effect over time as they can help reframe the policy debate. Ruckelshaus *et al.* (2015) argue that case study purposes evolve over the longer term as dynamic 'impact pathways'.

5.3 ES appraisal methods as value articulating institutions

In our framework in Figure 2, we illustrated the idea that value articulating institutions can be extended to all types of ecosystem appraisal methods, to the extent that they are used as input to resolve a governance problem (Vatn, 2009; Martín-López *et al.*, 2014). Our detailed examination of study purposes reveals different and sometimes unexpected types of value articulation. It has been argued that monetary methods predominate ecosystem service valuation, and predominate as inputs to decision-making (Martín-López *et al.*, 2014). The OpenNESS experience reveals that monetary valuation was applied in a small minority of case studies. Furthermore, where monetary valuation methods were applied, they were mainly conducted for informative purposes, in particular 'awareness-raising on the *importance of ecosystem services'* (Figure SM4.1). In the few cases that tested valuation in OpenNESS it stayed, as it were, at the TEEB level of "demonstrating value". This finding echos the decision-support gap in monetary valuation found by Laurans et al. (2013), but we have admittedly a very small sample. OpenNESS' sample of case study partners involved relatively few with economic valuation expertise. Looking at detailed purposes it is also interesting to note that mapping was conducted, as we would expect, for informative purposes ('current state', 'awareness of ES importance'), but also for decisive purposes at a similar level of importance as 'synthesising' methods (l.l.h. panel Figure SM4.1). Within the group of decisive purposes, mapping methods were predominantly conducted for *'spatial targeting'*, but notably also as *'arguments for negotiation, shared norms & conflict reduction'*. This provides support for the assertion that mapping can also be a tool for framing and articulating values (Figure 4.2) (Hauck *et al.*, 2013; Martín-López *et al.*, 2014). This was particularly true in OpenNESS where a number of participatory mapping methods were tested.

5.4 Integrated ES appraisal and cumulative uncertainty

Figure 4.3 provided the background for discussing cumulative errors and reliability when integrating across a cascade of ES appraisal methods. It provided the basis for our information cost hypothesis (Figure 4.4). We found some support for our hypothesis in the ordering of study purposes across OpenNESS, but could not observe more detailed causal factors. The information cost hypothesis could be challenged in a couple of ways.

First, the constraints of data availability, information and resources are expected to be the strongest for novel decision-support problems. OpenNESS case studies often applied novel methods for their study sites, with *explorative* purposes being among the most important for mapping, modelling, and socio-cultural methods. Here, there may be a selection bias from the point of view of decision-makers in the case study advisory boards. Novel studies need to be *explorative* until their reliability is tried and tested. While methods are being tested they may also be *informative*, to the extent that engagement with stakeholders is actively pursued. However, it seems reasonable to assume that cautious decision-makers will be less likely to use novel methods for *decisive* and *technical design* purposes (despite researchers own perception of their methods' potential). Figure 4.3 suggests that

ES appraisal methods - and integrated valuation more widely (Jacobs et al. 2016) - must be percieved as reliable before being used by decision-makers to prioritise between alternative actions. Our contention is that OpenNESS' success as a research project in applying novel knowledge co-production methods with stakeholders, to some extent 'self-selected' away from *decisive* and *technical design* purposes. The exception may be the handful of 'synthesis' methods, including for example multi-criteria decision analysis (MCDA). Also, in some cases individual cases have actively evaluated *decisive* and *technical design* purposes, e.g. (Barton *et al.*, 2015; Dick *et al.*, 2016).

Secondly, a hypothesis about information costs suggests that encountering integrated ES appraisals that follow a cascading chain of model is unlikely (Barton *et al.*, 2016). As we increasingly integrate parallel ES appraisal methods with the aim of providing decision-support, we would expect stochastic events in the data to combine and generate – explicitly or implicitly - a joint probability distribution[10] of predicted policy outcomes. Decision-makers can make errors in decision-making whether ES appraisal information is qualitative or quantitative (Table 4.4). Rational decision-makers would be expected to balance the information costs of more ES appraisal against the information value of avoiding "costly actions" (Type I) or "missed opportunities" (Type II) decision errors.

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[10] Predicted to be normally distributed by the Centra Limit Theorem

Hypothesis testing outcomes of an action situation		Reality (ex post)	
		H0 true Costs > Benefits	H1 true Benefits > Costs
Valuation estimates (ex ante)	H0 true Costs > Benefits	«Status quo correct»	Type II error «Missed opportunity»
	H1 true Benefits > Costs	Type I error «Costly action»	«Action correct»

Table 4.4 The value of information for decisive purposes – how much does it contribute to reducing the likelihood of "costly actions" or "missed opportunities"

Uncertainty – poor accuracy and reliability of ES appraisal - can lead to "costly actions" or "missed opportunities". Table 4.4 defines type I and type II errors, respectively.   A 'well-defined' decision is one in which action alternatives, their benefits and costs, can be defined sufficiently to test a null-hypothesis about the net benefits of an action (e.g. landuse change). Information value can be measured in terms of reducing the likelihood of making a type I or II error, multiplied by the foregone benefits or avoided costs of those errors.   Appropriateness of integrating further information (appraisals) is then a question about whether this value outweighs additional information costs.

But what happens if biophysical, socio-cultural and monetary methods are conducted in parallel, as individual plural value inputs to integrated valuation (see chapter 3 and Jacobs et al. in press)? Do we see cumulative effects of uncertainty and information costs when valuation methods are conducted in parallel? While errors may accumulate in a governance hierarchy, a basic reason for institutions is also to manage risk (Vatn, 2015). When institutions can sequence appraisals – e.g. explorative > informative > decisive > technical design -   a mitigation of increasing information costs is possible and even likely, as options and alternatives that need to be considered are reduced.   Furthermore, individual ES appraisals are often requested which do not link together in terms of input-output in chains of models. Because these studies do not depend on quantitative input from oneanother, uncertainty is not cumulative in the sequential sense illustrated in Figure 4.3. Nevertheless, a comparison of costs and benefits of actions – whether quantitative or qualitative - requires some kind of mapping-modelling-valuation synthesis procedure (IPBES, 2015). Even if a synthesis procedure is qualitative, if is conducted to support decisions, it is subject to uncertainty about outcomes and the logic of Table 4.4. In a qualititative sense of weighing arguments for different alternative courses of actions, a rational decision-maker would still consider the balance of evidence in pro and contra of actions, compared to the costs of obtaining further qualitative information about those actions.

6. Conclusions - narrowing the gaps in (dis)integrated valuation

Jacobs et al. (2016, p.5) pose three priority questions for ES appraisals to move towards integrated valuation with real societal/policy impact. Some of the findings of this chapter speak to those questions.

"Priority 1. (How to) Achieve inclusion of stakeholders and decision makers in research design and knowledge production, to include hidden values, deal with power asymmetries and improve societal relevance of the valuation results". We find that knowledge co-production and awareness raising were the most successful aspects of the OpenNESS project's case studies. However, on average the case studies were significantly less successful with study design and participation in method selection, even when controlling for the degree of case study advisory board participation. While some case studies had built long-term relationships with stakeholders prior to OpenNESS, we did not observe that the length of those relationships had an effect on the degree of study co-design or method co-selection with stakeholders. We can assume that other factors, such as the co-design approach used, or the cultural context of a specific case study (e.g. participatory fatigue or generally low willingness to participate) have considerable influence too. Knowledge co-production is a necessary, but not sufficient condition of integrated valuation.

"Priority 2. (How to) Combine a set of appropriate methods, disciplines and new approaches to obtain more comprehensive, acceptable and credible valuation results". The credibility of ES appraisal results is facilitated through knowledge co-production with stakeholders, but it is not sufficient. Acceptability of ES appraisals also depends on the reliability and accuracy of the method relative to type of governance problem that is being addressed. In OpenNESS we found support for the hypothesis that requirements for reliability and accuracy may be lower for *explorative* and *informative* purposes, than for *decisive* and *technical design* purposes. Although we were not able to measure the effect of information costs directly on method choice, we think that increasing reliability and comprehensiveness come at the price of increasing information costs. This is a challenge for integrated valuation. It should be a research question to further narrow the operational gap in ES appraisals.

"Priority 3. (How to) aim for and evaluate societal impact of integrated valuation studies, to advance effective contribution of science to societal challenges" [..] *"any decision based on integrated valuation is likely to be more fair, sustainable, credible, legitimate and effective than a decision informed by single-value methods."(p.5)*. Based on our experiences in OpenNESS case studies we would qualify the preceding statement. Individual ES appraisal methods (articulating single-values) are at one end of a continuum that stretches to full integration, as illustrated by the fully linked sequential methods in the rational actor governance model (Figure 4.1). Decision problems are also ranged along a continuum from less to more complex depending on spatial scale, resolution and purpose (Gómez-Baggethun and Barton, 2013). In very local settings with a single stakeholder it is conceivable that a single appraisal method will represent the appropriate level of integration. Simply adding valuation methods, and increasing value plurality, will not by itself solve complex ecosystem management problems. Integrating additional methods may be more costly than the additional value of information gained, when compared to the benefits and costs that are at stake. Some type of synthesis is needed, and some synthesis methods provide more value of information than others. We

therefore think that further research is needed on method *information cost* and *information value,* and that these should be added to the list of considerations regarding the appropriate level of integration in ES appraisal.   Information costs are part of the 'instrumental criteria for method selection' called for by Jacobs et al. (2016). In the case of *decisive* purposes, where ranking of decision alternatives is the governance problem, rational decision-makers would balance information cost against information value with the aim of avoiding "costly actions" or "missed opportunities". We recognise that the rationality of stakeholders depends on whether their objective is to improve decision-making for societal purposes, or whether it is 'influence-making' in situations of power asymmetry and environmental conflict (Laurans and Mermet, 2014). Furthermore, synthesis of information to support policy decisions represents power. If this is a power that decision-makers want to reserve for themselves, research will have a mandate only to 'explore' and 'inform' (rather than 'decide' and 'design').   Despite such possible constraints, we would argue that OpenNESS has shown that self-reflection on information costs, and the active pursuit of knowledge co-production with stakeholders, has contributed to narrowing the operational gap, moving in the direction of integrated valuation.

7. Epilogue

Chapter 4 was peer reviewed for publication in Ecosystem Services and several improvements were made. Reviewers found the three frameworks in section 2 distracted from the discussion of the case study findings. Reviewers also found the qualitative data from the case studies was too weak to support an 'information cost hypothesis'. In the final paper we formulated a theory of expected cumulative uncertainty in integrated valuation, providing a basis for an information gap hypothesis. Information costs are one of several possible indicators of an information gap in integrated valuation.   We also discuss other interpretations of integrated valuation – including plural value integration – making better use of the findings from Chapter 3 in this report.

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Supplementary Material

Table SM4.1 definition of methods

Mapping (n=24)	Biophysical Modelling (n=10)	Monetary valuation (n=12)	Socio-cultural valuation (n=25)	Synthetising methods (n=9)
ESTIMAP is 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); **Matrix approaches** 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 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	**SITE Landuse model** (SImulation of Terrestrial Environments mode is based on a cellular automata approach, in which the biophysical environment is represented by a grid. Simulated land-use decisions are based on a multicriteria suitability analysis of (i) the natural environment and (ii) the socio-economic conditions (Priess *et al.*, 2007) **Bayesian belief network** BBNs are based on simple diagrams consisting of nodes representing processes or factors, and links showing how the processes are connected, typically derived using expert knowledge. For ecosystem service assessment, the nodes may represent factors determining the supply or demand of sevices, such as land cover or soil type, as well as outcomes such as water flow, and information on values and preferences. Each link is assigned a weight to indicate the probability that the link is true, or the strength of the causal relationship, so that uncertainty is explicitly taken into account (see Smith et al. in press).	**Time use value** Visitors time use at recreation sites is obtained through a survey, and multiplied by a monetary estimate of time value, for example average wage rate after taxes. **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 Barton, 1999). **Cost-based,** 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**	**Questionnaire & 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 & Berkes 2014). **Photoseries 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 & Friess, 2015). **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). **Time use** This method is an innovation of the conventional stated preference techniques taken from the contingent valuation	**Integrated mapping-modelling (INVEST, EcoServ)** 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). EcoServ-GIS is a Geographic Information System (GIS) toolkit for mapping ecosystem services at a county or regional scale. It uses input GIS/map data to generate fine-scale maps that illustrate human need or demand for ecosystem services as well as the capacity of the natural environment to provide them. http://ecosystemsknowledge.net/ **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 & Hauck 2015). **Multi-criteria decision analysis** MCDA is an umbrella term to describe a collection of formal

spatial datasets grouped into themes combined with both scientific experts' and local actors' scorings. **QUICKScan,** an interactive GIS-based modelling tool 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. 2012); **Smarthphone Apps** Blue-green factor app let's a smarphone user map and scores blue-green structures at property level and compare with minimum zoning requirements. ESM-App/MapNat lets smartphone users map important places, paths and polygons for ecosystem services **PPGIS** Participatory GIS (PGIS) or Public Participation GIS (PPGIS) is a form of deliberative mapping. It uses web-based surveys, face to face interviews and workshops 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).	BBNs can be linked to GIS to undertake spatial analysis. **Climate envelope modelling** Species distribution models (also known as climate envelope or niche models) are used to project the potential impacts of climate changes on species. They are correlative models, based on the statistical relationship between a species' distribution and the climate, with the assumption that the species' distribution is in equilibrium with the climatic conditions. **Hydrological models,** hydrological models, such as the Soil and Water Assessment Tool (SWAT; Francesconi et al. 2016); **Meta-analysis** based on systematic literature review advantages and trade-offs of ES and biodiversity from similar studies were applied to a number of silivcultural research plots and current management prescriptions(Soler *et al.*, 2016)	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** Stated preference valuation is a family of 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).	approach. 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). **Q-method** a research method used in psychology and in social sciences to study people's "subjectivity" using a form of factor analysis to look for correlations between subjects across a sample of variables **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 & Howarth, 2002). **Stakeholder analysis** Ecosystem services scoring using card game **ES cascade focus group**	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. **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).

SM4.3 Selected stakeholder survey questions

Question wording for stakeholder survey questions reported in this chapter are given below where not reported in the chapter text itself.

1. Please rate your level of participation in the OpenNESS Oslo case study*

1.1 I participated in problem framing of the research conducted

1.2. I participated in the selection of research methods/approaches used

1.3 I participated in co-production of knowledge (i.e. attended workshops/meetings/ stakeholder engagement activities)

1.4. I was fully informed about results

1.5 I am a member of the Case Study Advisory Board

1.6. I participated in another way. Please specify:

3. Please rate your role in relation to the issue investigated: mapping and evaluation of ecosystem services from urban blue-green infrastructure*

3.1. I make decisions related to the issue investigated

3.2 I contribute to decision making related to the issue investigated

3.3. I am affected by the issue investigated

3.4. I am interested in the issue investigated

3.5. I have another interest not mentioned above (Please specify)

*Responses scored level of applicability as Not applicable -Little bit applicable -Somewhat applicable –Applicable -Very applicable

8. Please rate your assessment of the intended or already realized use of the OpenNESS research

The OpenNESS research on "operationalising the ecosystem service and natural capital concepts" resulted in the following*:

8.1. The OpenNESS research resulted in a change in future vision in the area (e.g. vision document on the future landscape, policy etc.)   (e.g. vision document on the future landscape, policy etc.)

8.2. The OpenNESS research resulted in a change in the way information and tools are used to support decisions

8.3. The OpenNESS research resulted in a change in decision making

8.4. The OpenNESS research resulted in a change in actions

8.5. The OpenNESS research resulted in another positive or negative impact(s).
 Please specify:

*Responses scored as It is very unlikely to take place -   Probably not take place -Not sure - It will probably take place - It already took place
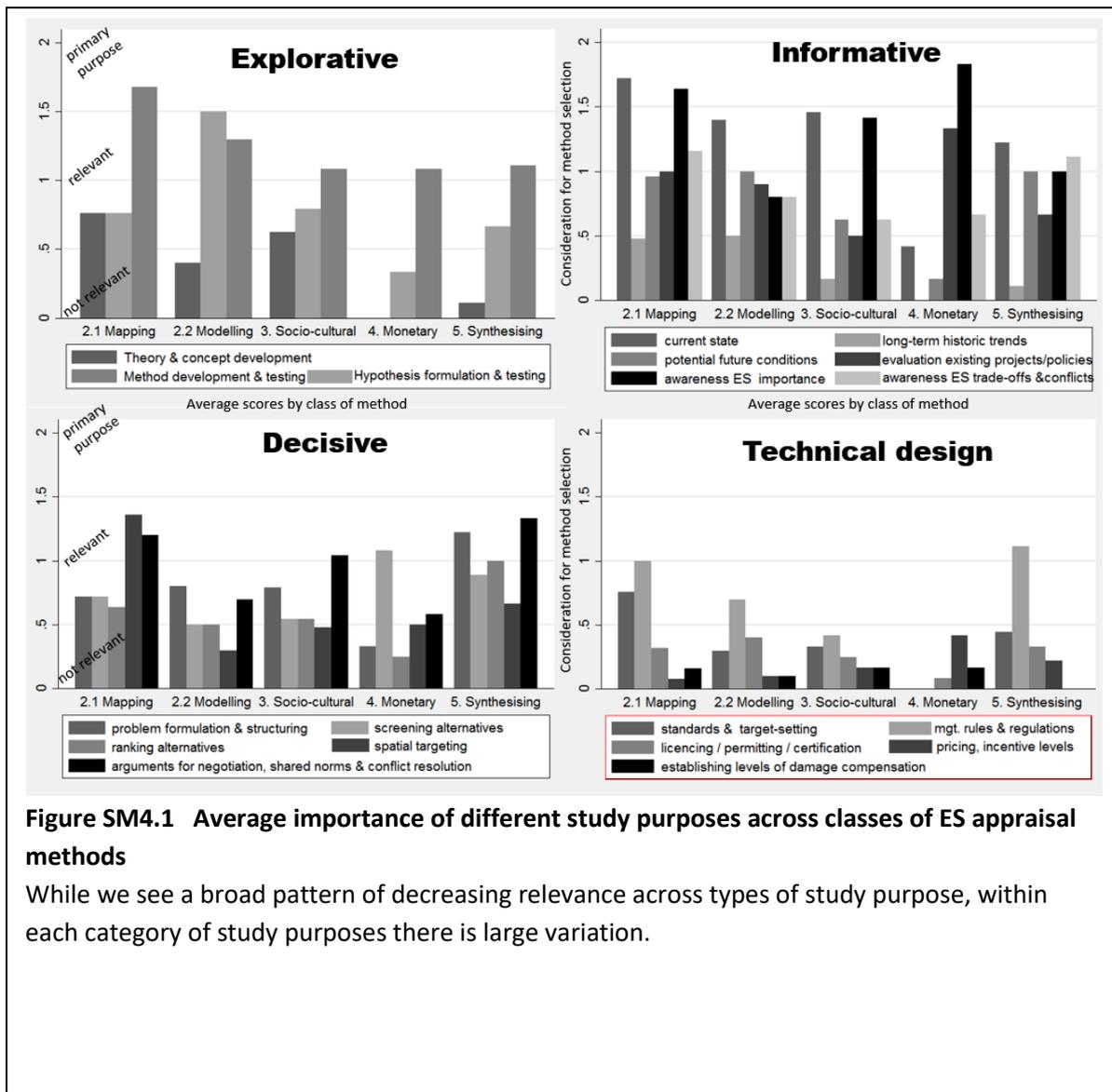
Figure SM4.1   Average importance of different study purposes across classes of ES appraisal methods

While we see a broad pattern of decreasing relevance across types of study purpose, within each category of study purposes there is large variation.
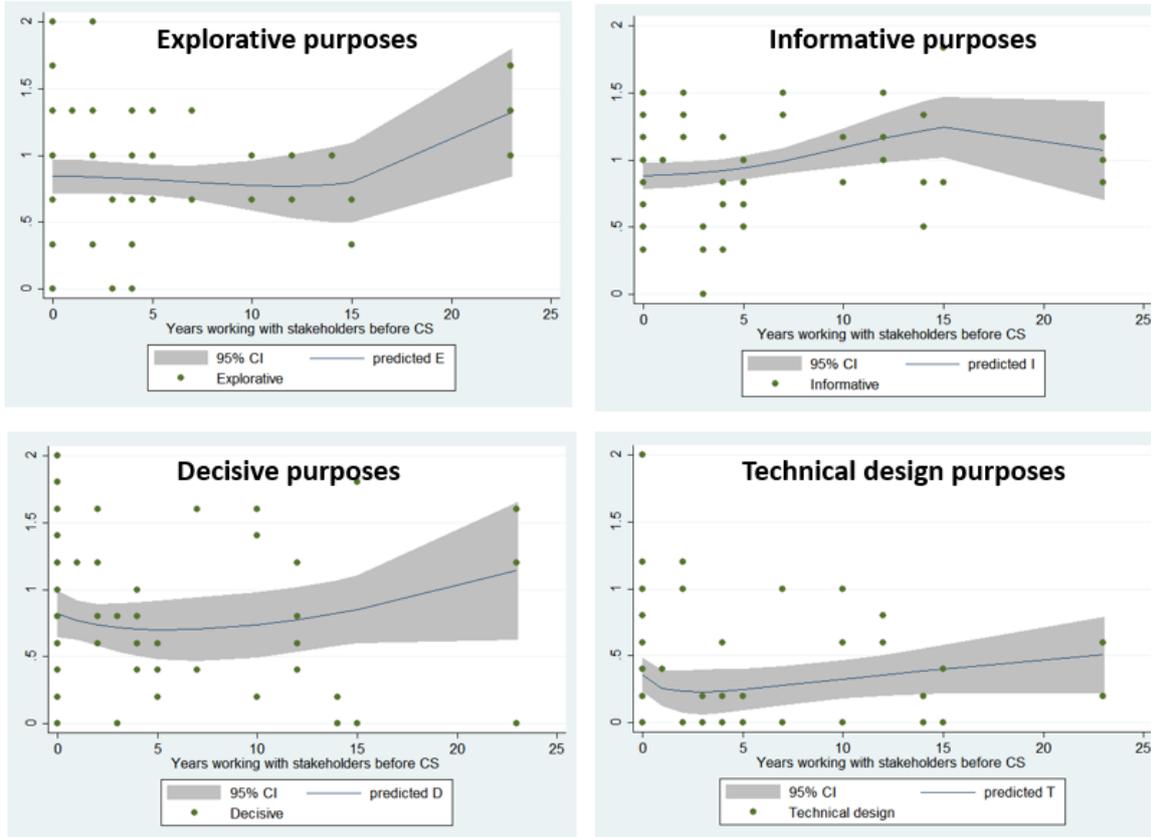
Figure SM4.2 Do more challenging purposes of ES appraisal increase with stakeholder-researcher familiarity ? (multinomial function fit with confidence intervals 95%)

There are no clear correlations between decisive or technical design use of ES appraisal methods and years researchers have worked with stakeholders before the OpenNESS case study started.

make decisions / contribute to decision making / affected / interested

Figure SM4.3 Stakeholder participation in decision-making in the case study area

The stakeholders who interacted with researchers in case studies had diverse roles with regards to decision-making on ecosystem services management. Figure S3 shows the proportion of respondents in the stakeholder survey who "make decisions", "contribute to decision-making", are "affected" by or "interested" in ecosystem services issues assessed by the case studies. A bit less than half of the stakeholders interviewed "make decisions" about the ecosystem services investigated, while over half "contribute to decision-making". The majority of stakeholders were "affected" by or "interested" in the ecosystem services issues assessed in the case studies.

change in future vision in the area

change in the way information and tools are used to support decisions

change in decision making

change in actions

Figure SM4.4 ES appraisal methods' impact on decision-making and actions

Figure SM4.4 shows how the stakeholders as a group assessed the impact of the ES appraisal methods applied in the case studies.   A majority of stakeholders found that appraisal methods lead to a "change in future vision in the area", "change in the way information and tools are used to support decisions", "change in decision-making" and "change in actions".   The proportions were slightly lower when it came to actual decision-making or action taking place.

participated in problem framing

participated in the selection of research methods

participated in co-production of knowledge

fully informed about results

Legend:
- not applicable
- somewhat applicable
- very applicable
- little bit applicable
- applicable

Figure SM4.5 Stakeholder participation in study design and method selection

Figure SM4.5 shows the extent to which stakeholders as a group partipated in "problem framing", "method selection", "co-production of knowledge" (i.e. attended workshops/meetings/ stakeholder engagement activities) or was simply "fully informed about results". A minority of stakeholders participated in problem framing or selection of methods.

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METHOD SELECTION TOOL ONLINE

http://openness.hugin.com/oppla/MethodSelection

Spread	ESTIMAP	BBN	STM	QUICKS	InVEST	Species	ECOPLAN	RUSLE	BG	MapNat	PA	EcoChain	GLO-ES	IAP	Time	Pref	PE	SMAP
DV	CARD	Narr	Scen	Prod	Shadow	Cost	TCM	HP	SP	Transfer	MCDA	BBN DS	PPGIS	OE	TESSA	Vol	Bus	IBAT
Eco	Web	IODINE	WWF	LCA	ToSIA	mDSS	BackES	LANDS	PES	PA	SEEA	EHS	O/NNL					
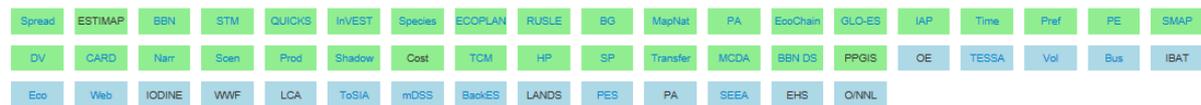
OPERA methods OpenNESS methods

Context   Scale   Data   ES   Resources   TEV   **BBN**

BBN

GeneralPurpose

34.59% Information

55.35% Decision-support

10.06% Management instruments

Purpose

49.78% Awareness raising

0.75% Accounting

47.96% Priority setting

0.75% Instrument desing

0.75% Liability

Monetary_result

51.89% no

48.11% yes

Option_values

30.66% Highly appropriate (designed for this)

21.23% Less suitable (implying conditions)

11.79% Not appropriate (risk biased outcomes)

36.32% Suitable (without severe conditions)

Bequest_values

11.79% Highly appropriate (designed for this)

28.77% Less suitable (implying conditions)

17.45% Not appropriate (risk biased outcomes)

41.98% Suitable (without severe conditions)

Existence_values

method

1.89% Our ecosystem

1.89% TESSA: toolkit for rapid assessment of ecosystem services at sites

1.89% STREAMLINE

1.89% Business information tool — LCA, labelling and others accounting and rating systems being explored

1.89% IBAT information tool

1.89% Ecosystem services indicator development3

1.89% Web-based Scenario Toolbox

1.89% CBA - Cost Benefit Analysis (IODINE)

1.89% CBA - Cost Benefit Analysis (WWF)

1.89% LCA - Lifecycle Assessment

1.89%

FACTSHEETS:

INTEGRATING METHODS

Scenario planning

Introduction

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' (Priess & Hauck 2015). Scenarios can be developed with the help of expert input or wider public participation, and can take various shapes, including qualitative or quantitative scenarios, exploratory or anticipatory scenarios, and baseline or policy scenarios (Alcamo 2001). Scenario planning is one branch within the broader field of Futures Thinking, including diverse methodological approaches (Marien 2002). In scenario planning, various tools and techniques are applied (often in combination) to develop plausible and internally consistent descriptions of alternative future options (Johnson et al. 2012). Assumptions about future events or trends are questioned, and uncertainties are made explicit (Bohensky et al. 2006). Scenario planning typically takes place in a workshop setting, where participants explore current trends, drivers of change and key uncertainties, and how these factors might interact to influence the future (Schoemaker 1995). Although scenario planning is not a de facto valuation tool, scenarios can be used to explore how ecosystem services might change in the future and how these changes can influence human well-being. Therefore by comparing and evaluating scenarios we can also reveal the value of related ecosystem services.

Keywords

Future thinking; Uncertainty; Decision support; Public engagement; Value plurality.

Why would I chose this approach?

Scenario planning is primarily used as a decision support tool. It can be used to assess the possible future impacts of various drivers of change (including external drivers such as climate change or internal drivers such as different policy interventions) (Priess & Hauck 2014). Scenarios can combine qualitative and quantitative data collected from various information sources. They can take into account uncertainty and complexity inherent to many decision making situations, especially if a larger time horizon is involved in the decision (Peterson et al. 2003). The process of scenario development – if it follows a participatory approach – can accommodate creative thinking and social learning (Johnson et al. 2012), and can therefore support joint problem definition and consensus building (Priess & Hauck 2014).

Most cases found in the literature assess only a few selected ecosystem services as part of scenarios (Hauck et al. 2015), but scenario planning can also apply a comprehensive approach to ecosytem services when assessing the possible consequences of changes in ecosystem services provided at a certain place (see e.g. the MA scenarios). Scenarios can also highlight the bundles and trade-offs

between key ecosystem services, by indicating how they might change under common conditions (i.e. whether they change together or on seperately).

The spatial scale at which scenario planning has been applied in the ecosystem services literature ranges from the local to the global (Alcamo et al. 2008). Different spatial scales can be combined in multi-scale scenarios (Kok et al. 2007). Spatial resolution is highly variable depending on the tools and approaches used during the process. If scenarios are developed in a participatory way using various knowledge forms and described primarily in qualitative terms, spatial resolution might be coarse. If scenario narratives are used as inputs to modelling, scenarios can be translated into fine-tuned, spatially explicit quantitative estimations (depending on the availability of data and expertise). As a result of this, scenario planning can be a useful decision support tool for awareness raising (by knowledge sharing, see e.g. Johnson et al. 2012), priority setting (by comparing and evaluating future alternatives, see e.g. Geneletti 2012) and instrument design (by discussing the range of policy options and managing the potential conflicts between them, see e.g. Palomo et al. 2011, Pearson et al. 2010).

What are the main advantages of the approach?

- Addresses complexity and uncertainty in a transparent and creative way;
- Facilitates learning and allows for the integration of diverse knowledge forms and plural and heterogeneous values;
- Well-established approach, there are global and regional scenarios available in the literature (e.g. IPCC, MEA, IPBES is in progress) which can be used for comparison and down-scaling;
- Scenarios can be developed in a participatory way which makes possible the active engagement of different stakeholders and hence can create a science-policy-public interface;
- It is possible to consider a range of policy or response options, and assess how robust those options are to the different scenarios developed.

What are the constraints/limitations of the approach?

- Robustness and internal consistency of scenarios is a key requirement which can only be guaranteed if quality control mechanisms are built in the process;
- The quantification and modelling of narrative scenarios is often highly demanding in terms of expertise, time and other resources;
- A participatory scenario planning process requires good facilitation skills and resources;
- Participatory scenario planning is time consuming for local stakeholders.

What types of value can the approach help me understand?

Scenario planning can help reveal diverse and heterogenous values, including ecological, sociocultural and monetary values. It is especially suitable for including future-related values such as option and bequest values. It has however some limitations for incorporating the intrinsic values of nature – to this end combining scenarios with biophysical modelling might be necessary.

How does the approach address uncertainty?

Uncertainty is explicitly addressed by creating and comparing different plausible futures. It can be tackled both qualitatively (in scenario narratives) and quantitatively.

How do I apply the approach?

For detailed information on how scenarios can be developed see the OpenNESS synthesis paper on scenarios (Priess & Hauck 2015). Here we sketch out a general stepwise approach including the major phases of an integrative scenario development process (adapted from Priess & Hauck 2015).
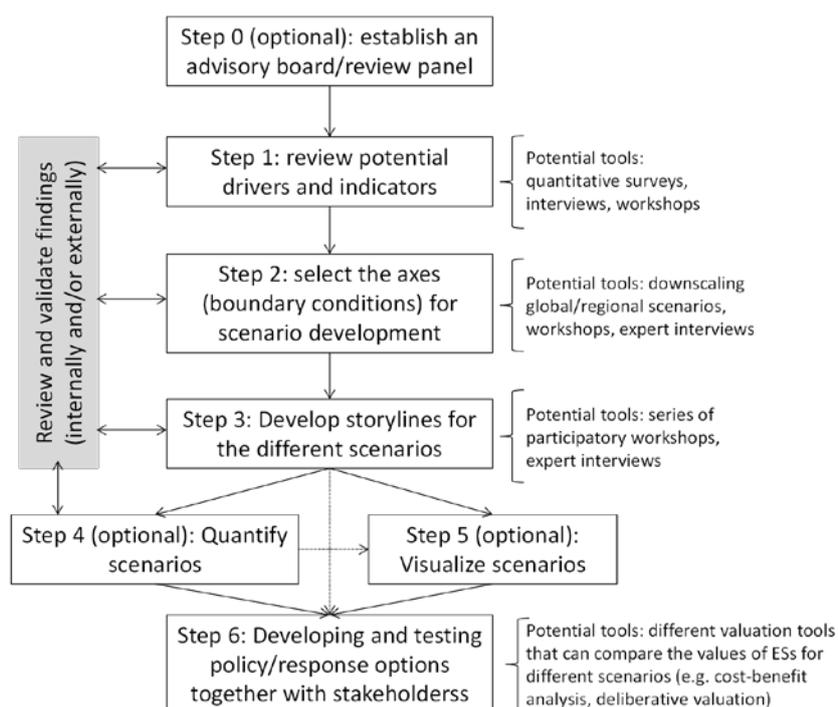

Figure 1. Steps for developing and using Scenarios for decision support around ecosystem services.

Requirements

Requirements		Comments
Data	☐ Data is available ☐ **Need to collect some new data (e.g. participatory valuation)** ☐ **Need to collect lots of new data (e.g. valuation based on surveys)**	Data requirement depends on the type of scenario and availability of existing data. Qualitative scenarios require less data which can be collected through participatory workshops. Quantitative scenarios might need extensive numerical data input.
Type of data	☐ **Quantitative** ☐ **Qualitative**	Scenarios can be both qualitative (summed up in narratives, images, screenplays) and quantitative (including numerical information in forms of graphs, tables and maps).

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Expertise and production of knowledge	☐ **Working with researchers within your own field** ☐ **Working with researchers from other fields** ☐ **Working with non-academic stakeholders**	Scenarios can be developed solely based on scientific knowledge, although including various disciplines and the general public can increase the robustness of scenarios.
Software	☐ **Freely available** ☐ **License required** ☐ **Advanced software knowledge required**	Depends on the type of scenarios qualitative/ participatory scenarios does not need any extra software support, quantitative scenarios might require licensed software and always necessitates advanced modelling/ programming skills
Time resources	☐ **Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	(It might require more time if stakeholders are heavily involved in a series of workshops or if special data has to be collected).
Economic resources	☐ Low-demanding (less than 6 PMs) ☐ **Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	(This will vary depending on the tools applied).
Other requirements	Special expertise might be necessary if scenarios are combined with modelling and/or mapping (computation, modelling) or scenarios are developed in a participatory way (facilitation skills)	

Where do I go for more information?

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Factsheet prepared by Jennifer Hauck and Eszter Kelemen

METHOD FACTSHEET

Object-Oriented Belief Networks (OOBN)

Introduction

Bayesian belief networks are not a valuation method per se, but an approach to synthesising valuation and ecosystem function knowledge for decision support. Bayesian belief networks (BBNs) are useful for:

(i) Eliciting stakeholders understanding of cause-effect linkages in a visual network and formalising their knowledge of the strength of effects as a series of conditional probabilities.

(ii) Linking biophysical and socio-economic model input-outputs together in a consistent ecosystem services cascade or driver-pressure-state-impact-response chain, handling cumulative uncertainty consistently using a series of conditional probability tables making reasoning with uncertainty possible, and

(iii) Analysing costs and benefits of decisions in terms of cost-effectiveness analysis (CEA), cost-benefit analysis (BCA) and multiple criteria analysis (MCA).

Sub-networks representing sub-model input-outcomes can be represented as model 'objects within another BBN – producing a hierarchical model called an Object-Oriented Bayesian Network (OOBN). Other fact sheets address OOBNs in the context of (i) and (ii) while this fact sheet addresses (iii). When variables (nodes) for costs and benefits (utilities) are added to chains of conditional probability tables (representing ecosystem functions) BBNs are called "influence diagrams" (Kjærulff and Madsen 2007).

Keywords

Object-oriented Bayesian networks; Influence diagrams; Cost-effectiveness; Cost-benefit; Multi-criteria analysis; Decision-support.

Why would I chose this approach?

OOBNs make it possible to link 'upstream' costs of decisions to 'downstream' benefits of those decisions, making use of all available information, and accounting for the cumulative uncertainty of using information sources of different quality. This makes it well-suited for operationalising the ecosystem services cascade framework (Haines-Young 2011, Landuyt, Broekx et al. 2013). OOBNs for decision-making are useful where more than one biophysical model needs connecting to costs and benefits of decisions (Barton, Kuikka et al. 2012). In principle, any ecosystem service can be addressed by this generic tool. In practice it has seen many applications to watershed management, looking at model chains from upper catchment to downstream impacts in water bodies (Barton, Saloranta et al. 2008). As the interface between BBNs and GIS improves OOBNs are seeing greater use in studying ecosystem service impacts spread over a landscape – these are spatially disaggregated BBNs. This means that applications for, e.g., cultural ecosystem services, are likely to increase in future.

OOBNs are useful for 'priority-setting' under uncertainty, combining information from different approaches to valuation. OOBNs are generic and can be applied to any spatial scale.

What are the main advantages of the approach?

Methodological advantages
- Trans-disciplinary;
- A knowledge integration tool that integrates qualitative and quantitative data;
- Draws on existing data (monitoring, modelling);
- Formalises expert judgement;
- Explicit modelling focus on the relationships between model resolution and uncertainty;
- Manages missing information.

Governance advantages
- Integrated valuation modelling tool;
- Covers wide range of ecosystem services;
- Can address a wide range of impact/values types;
- Participatory approach with stakeholders;
- Trade-offs can be evaluated;
- Uncertainty can be addressed (diagnose 'garbage-in-garbage-out' problems).

What are the constraints/limitations of the approach?

Methodological constraints
- Discretization of data can lead to information loss (but this is a common features of all models, while in BBNs it is directly observable);
- GIS integration is limited but improving;
- Handling of time series and feedback effects is limited, but improving (time sliced models).

Governance constraints
- Information loss in each modelling link and cumulative uncertainty analysis leads to a bias towards 'no action' or status quo decision alternatives.

What types of value can the approach help me understand?

Bayesian belief networks are suitable to most value categories independent of which value typology we take into account. Because it is a generic method it has limitations common to other quantitative methods in eliciting non-anthopocentric values of nature, as well as bequest and existence values.

How does the approach address uncertainty?

A BBN is a representation of a joint probability distribution where uncertainty is represented as conditional probability distributions in a network diagram. In a graphical user interface (example in Figure 1, below) posterior distributions given observations are shown for each variable.   OOBNs strength lies in describing uncertainty – variance that is generated from spatial heterogeneity and temporal variation - meaning that OOBNs spatial and temporal resolution is often coarse and they are most useful for synthesising 'large data' problems. If high-resolution modelling of ES is required – it is better to use bespoke biophysical models. OOBNs makes them ideal for the kind of synthesis that is needed for assessing decision alternatives across landscape variation.
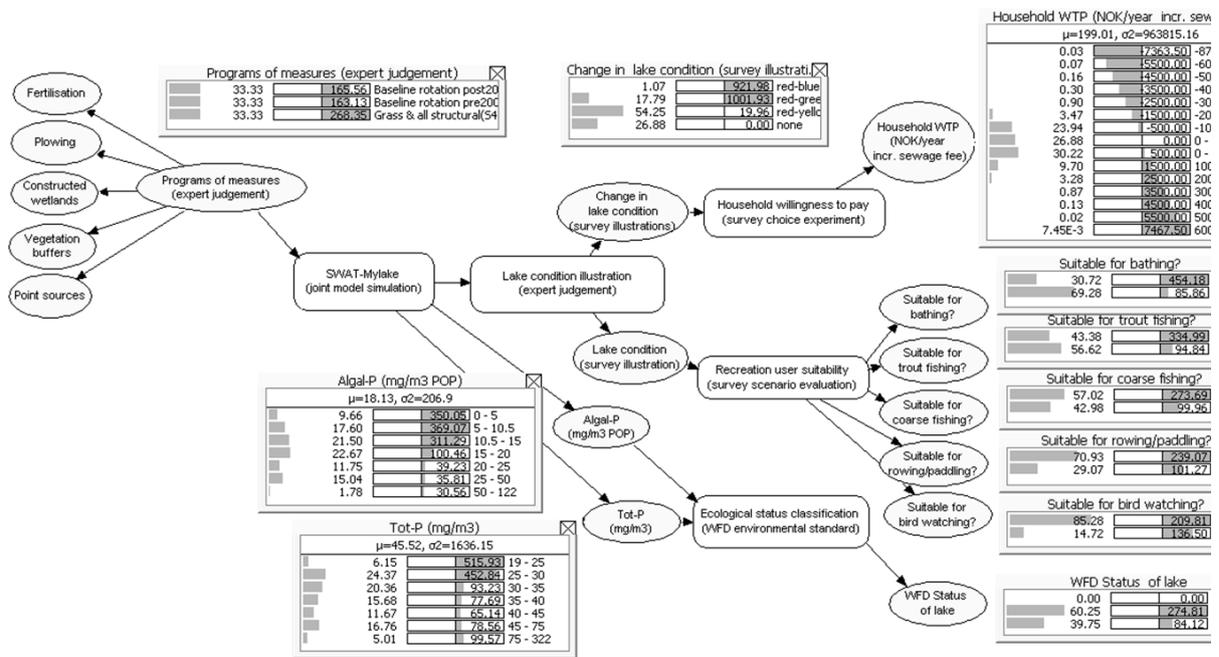
Figure 1. Graphical user interface of an Object-oriented Bayesian Network. Rectangles are sub-models 'objects' that are linked together in a joint probability distribution. Ovals are conditional probability distributions with their information displayed in monitors; bars on the left are probability distributions, bars on the right are expected utilities of each state of the variables.   Source: Barton et al. 2016.

How do I apply the approach?

The generic modeling steps for setting up a BN for decision support are briefly as follows:
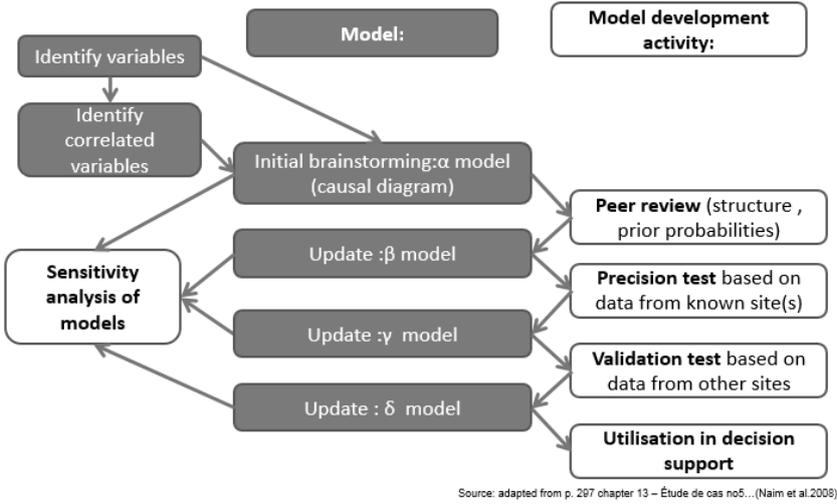
Figure 2. Stepwise approach to OOBNs. Source: Naim, Wuillemin et al. (2007)

Requirements

Requirements		Comments
Data collection requirement	☐ Data is available **X Need to collect some new data (e.g. participatory valuation)** ☐ Need to collect lots of new data (e.g. valuation based on surveys)	
Type of data required	**X Quantitative** ☐ Qualitative	
Expertise and production of knowledge needed	☐ Working with researchers within your own field **X Working with researchers from other fields** **X Working of non-academic stakeholders**	
Software requirements	☐ Freely available **X License required** ☐ Advanced software knowledge required	HUGIN, Netica, Bayesia, BayesFusion, Quickscan
Time requirements	**X Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	When data and parametrised models are available
Economic resources	☐ Low-demanding (less than 6 PMs) **X Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	
Other requirements		

Where do I go for more information?

Contact: david.barton@nina.no

BBN examples applied in OpenNESS can be found at http://openness.hugin.com/

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Factsheet prepared by David N. Barton and Anders L. Madsen

Multi-criteria decision analysis (MCDA)

Introduction

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" (Belton and Stewart, 2002, p. 2). The basic idea of MCDA methods is 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 human judgment and preferences. They are rooted in operational research and support for single decision-makers but recently the emphasis has shifted towards multi-stakeholder processes to structure decision alternatives and their consequences, to facilitate dialogue on the relative merits of alternative courses of action, thereby enhancing procedural quality in the decision-making process (Mendoza and Martins 2006).

Keywords

Multi-criteria decision analysis; Multi-criteria evaluation; Decision support tools; Non-monetary valuation.

Why would I chose this approach?

MCDA methods are used to address complex decision-making situations with multiple and often conflicting objectives that stakeholders groups and/or decision-makers value differently. A typical example of a decision-making situation assisted by MCDA methods is determination of an appropriate water regulation policy, which has a variety of economic, ecological and social consequences regarded as desirable by some stakeholders (e.g. downstream farmers) and undesirable by others (e.g. recreational fishermen).

MCDA methods can be used to address trade-offs between multiple ecosystem services because they allow comparison of ecological objectives with socio-cultural and economic ones in a structured and shared framework. They can incorporate ecological criteria such as carbon sequestration and water quality; economic criteria such as costs and economic impacts of alternative courses of action; and socio-cultural criteria such as cultural heritage and aesthetic values. MCDA methods can also be used to combine information about the performance of the alternatives with respect to the criteria (scoring) with subjective judgments about the relative importance of the evaluation criteria in the particular decision-making context (weighting).

MCDA is a decision support tool and hence it has been mostly used for priority setting, i.e., ordering alternatives according to the participants' and/or decision makers' value positions. The results can be aggregated to present a single preference order of the alternatives for the whole group. However, this requires inter-personal comparison of how much we valuate various stakeholder groups'

opinions. The other option is a disaggregated way to illustrate how different stakeholders have weighed the criterion and consequently prioritized the alternatives, with an aim to better understand the various viewpoints related to the problem. The valuation element in MCDA (normalization and weighting) can also be used for awareness raising by enabling citizens/stakeholders/decision-makers to probe their preferences and underlying value positions. MCDA methods have been applied on local as well as regional and some cases also national level (see Kiker et al. 2005), mostly on a spatial resolution more than 10 km^2.

What are the main advantages of the approach?

- Covers wide range of ecosystem services;
- Trade-offs can be evaluated;
- Can facilitate multi-stakeholder processes, transparency and discussion about the subjective elements in policy analysis;
- Can structure an assessment along both cognitive and normative dimensions;
- Uncertainty can be addressed by sensitivity analysis.

What are the constraints/limitations of the approach?

- Representativeness (only a small group of stakeholders usually involved);
- Some criteria such as cultural heritage or provisioning services vital for sustenance might not be amenable for trade-offs;
- Allows manipulation and closing down of policy discourses if not used in participatory and transparent way;
- Requires commitment form stakeholder to be involved throughout the process.

What types of value can the approach help me understand?

MCDA is highly appropriate to elicit both anthropocentric and non-anthropocentric values, including ecological, sociocultural and monetary values of ecosystem services. Not all MCDA processes can however address incommensurable criteria such as rights and duties, hence their applicability is limited in the case of eliciting bequest values.

How does the approach address uncertainty?

Uncertainty can be addressed by sensitivity analysis.

How do I apply the approach?

The basic steps in a MCDA process are presented in Figure 1. The first steps are related to clarifying the decision context and structure the problem according to the objectives and evaluation criteria as well as the alternatives to be examined. The next step is the model building. In this step, the performances of the alternatives are assessed with respect to the criteria. The results are usually compiled into an impact matrix using natural measures (e.g. Euros or hectares), proxy measures (e.g. the number indicator species can be used as a yardstick of biodiversity); and constructed measures, which report the achievement of the objective using a scale tailored to the decision context (Keeney and Gregory, 2005). Next, the measurement values are translated into performance scores (scoring).

For example, in Multi-Attribute Value Theory (MAVT), this is carried out by constructing value functions for each criterion that normalize individual impacts to a common scale of comparison. The value functions define the preferences for each criterion 'internally', i.e., how much a person values incremental changes in the measurement values of a single criterion in different parts of the scale (intra-criterion evaluation). The next phase is weighting where participants are asked to assign weights to the evaluation criteria (MAVT), or rank them (Rank-based methods use ordinal scale instead of cardinal scale), according to their preferences and value judgments (inter-criteria evaluation). The outcome of the analysis is the overall value for each alternative reflecting its overall performance under all criteria taken together compared to the other alternatives. Under certain assumptions (see e.g. Keeney and Raiffa 1976), one can use an additive model to obtain the overall values for each alternative by multiplying the criteria-wise performance scores with corresponding criteria weights and then summing them up. The results can either be fully aggregated or disaggregated according to stakeholder groups (see e.g. Mustajoki et al. 2011).

Figure 1. The basic steps in a Multi Criteria Decision Analysis (MDCA).
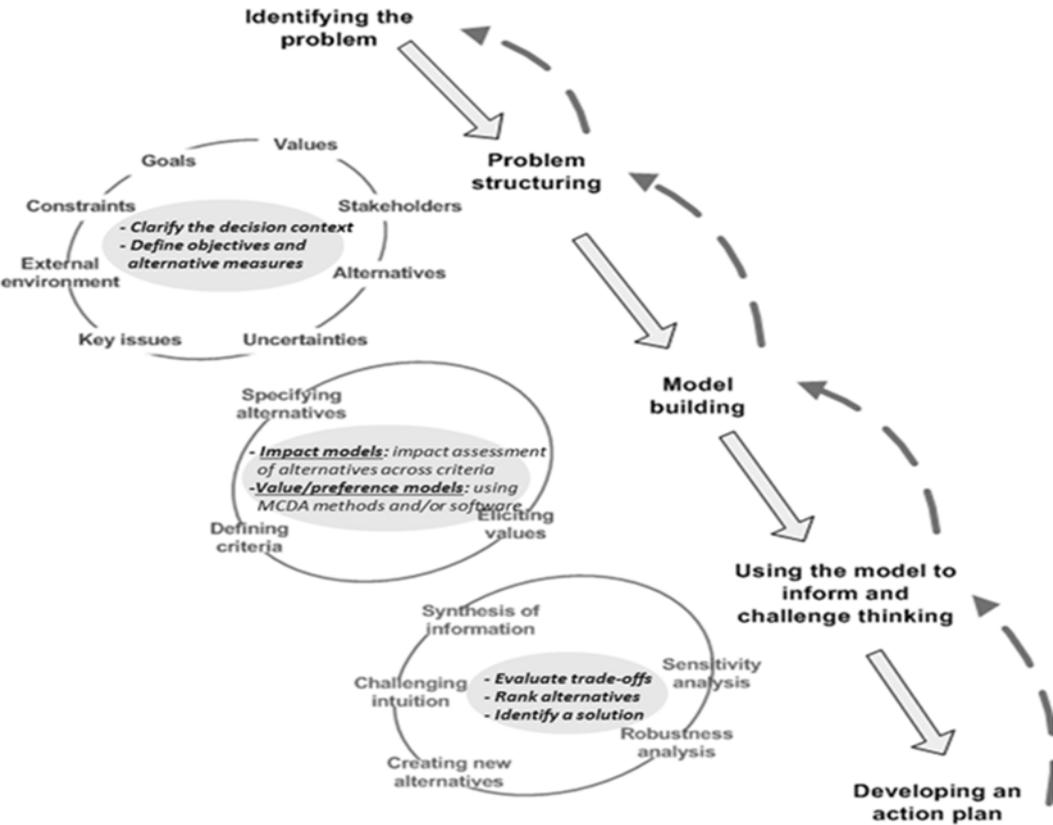
Source: adapted from Belton and Stewart (2002) by Catrinu-Renstrom et al. 2013

Requirements

Requirements		Comments
Data	☐ Data is available ☑ **x Need to collect some new data (e.g. participatory valuation)** ☐ Need to collect lots of new data (e.g. valuation based on surveys)	Participatory MCDA applications require a close contact with key stakeholders throughout the process, at least in the weighing stage. MCDA methods can make use of existing data but usually additional information (e.g. biophysical assessment or economic analyses) is required after defining the evaluation criteria with stakeholders.
Type of data	☐ x Quantitative ☐ x Qualitative	MCDA allows both for quantitative and qualitative information (scales can be used to translate qualitative information into quantitative scores).
Expertise and production of knowledge	☐ **x Working with researchers within your own field** ☐ **x Working with researchers from other fields** ☐ **x Working with non-academic stakeholders**	MCDA applications usually require interdisciplinary teams that work with stakeholder representatives
Software	☐ **x Freely available** ☐ **x License required** ☐ **x Advanced software knowledge required**	Some software are freely available but their use requires some software knowledge and knowledge on how to interpret the results.
Time resources	☐ **x Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	6-24 months.
Economic resources	☐ Low-demanding (less than 6 PMs) ☐ **x Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	MCDA processes can be carried out in less than 6 months if data is available and stakeholders can work intensively; it can also take more than 12 PMs, depending on the level of ambition and demands for preciseness.
Other requirements	Software and decision analyst to use the software is usually needed	

Where do I go for more information?

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Factsheet prepared by Heli Saarikoski and Hand Keune

QUICKScan

Introduction

Conceptual framework

The QUICKScan software and QUICKScan tool (http://QUICKScan.pro) encompasses a modelling environment with functionalities to assess societal and environmental conditions, diagnose patterns and interactions, implement alternative responses and evaluate the impacts of those responses. The QUICKScan modelling environment enables the linkage of GIS data to qualitative and/or quantitative rules and allows the user to identify not only the direct, but also the indirect, impacts of spatial strategies. It enables analyses of causes; the user can dynamically and interactively adapt the strategies and/or rules to reach a desired state. The QUICKScan framework addresses five questions (after Winograd 2007):

1. What aspects are relevant with respect to ecosystems and human well-being?
2. What typical 'pictures' of the past and current condition exist and what are the trends?
3. What elements and interactions are relevant for the persistence of these patterns, trends and impacts?
4. Which strategies and options can be devised to preserve, restore, use, improve, mitigate, or adapt?
5. Which hotspot areas, services or land covers could be identified as targets for policy actions?

General application of QUICKScan

QUICKScan is an empty modelling shell which needs to be filled on a case by case basis with GIS data, qualitative and/or quantitative rules, and map algebra. The tool is not restricted to a specific geographic location or spatial resolution; similar to word processing software (e.g. Microsoft Word) which is not restricted to a specific document (type). The system enables the definition of 'if..then..else' rules and links those to available data to create derived data. Typically the rules use quantitative classifications or qualitative typologies to help define the situation and options for change (Verweij et al. 2012). Rules may also be linked together to form a chain of rules. Alternative (chains of) rules are used to capture different options. Derived data from alternatives can be aggregated (e.g. by administrative units, or biophysical units such as catchments or climatic zones) to be displayed in tables and charts for overviews (see Figure 1 and http://quickscan.pro/features.html).

Figure 1. Collection of screenshots of the QUICKScan tool, showing its project library (1), rule definition (2), combinational workflow (3), and resulting maps and graphs (4).

Keywords

Participatory approach; Spatial approach; Modelling framework; Explore options/scenarios.

Why would I chose this approach?

The QUICKScan methodology is based on the use of an approach and a software tool that is applied in group processes with policy-makers and experts to develop and explore potential policy options and assess likely impacts of those options (Figure 1). A typical QUICKScan application is developed in three main steps:

1. Explore data related to the (policy) context: The system is populated with maps and statistics that the participants in a decision meeting find relevant to the policy question. The toolbox enables the data to be stored and described in an organised way, so that it can be viewed and compared in a clear way with users. This is usually done by the facilitators before a group session starts. During the workshop the maps and statistics are viewed and explained.

2. Design options and build workflows: Assess the impact of (jointly) defined policy options by defining 'if… then… else' expert rules. Expert rules can be quantitative and/or qualitative and are linked together to form a chain of rules. The tool will apply these rules to the maps and statistics creating indicators that show the likely impacts of the policy options.

3. Evaluate and iterate results: The derived data/indicators can be aggregated (e.g. by administrative or biophysical units) and displayed in tables, charts (including spider diagrams to show trade-offs)

and maps. The aim is to help the decision-makers and experts compare the impacts of different options, identify hotspots areas or issues and assess the trade-offs or alternatives. Often certain locations in the generated maps represent unexpected or puzzling results. The QUICKScan trace-feature lets the user trace back from the output maps to the applied rules. This is visualised by displaying the causal relationships between all used rules and GIS data resulting in the map and highlighting the decision path in each of the rules as applied for the location of interest. This helps to either explain the result or allows iterative fine-tuning of the rules. If needed iterations with new rules or for new options and alternatives can then be implemented.

What are the main advantages of the approach?

- QUICKScan is spatially-explicit.
- It can easily combine and handle a wide variety of different spatial data and knowledge rules.
- It has an open model structure with a direct response to all the implemented expert knowledge rules. This is often highly valued and seen as a possible future advance for more in-depth modelling approaches, e.g. the ease to test and trace back expert knowledge could not be replicated with current known standard GIS software without a lot of extra effort. The transparency of QUICKScan enables the easy transformation of the captured knowledge into other systems if/once this is judged feasible and desirable.
- It allows for the explicit and transparent implementation of all the calculation steps and knowledge rules required for addressing the impact of measures on ES and costs.
- It supports the use of Python for map algebra if this is required. The Python code can potentially be re-used in other programs or modules, if desirable at a later stage.

What are the constraints/limitations of the approach?

- Limited to spatially-explicit issues.
- No system dynamics, no feedback loops.
- Currently restricted to use with ArcGIS 10.0.
- It is developed for, and mainly used in, (relatively) short and participatory workshops. However, the tool can be deployed as an additional desktop tool alongside existing GIS software programs. For many basic GIS functionalities, QUICKScan cannot be compared with the performances of commercially available GIS packages. It is questionable if a (pure) desktop application of QUICKScan is therefore of much added value.
- Defining solid causal relations to express final output indicators, related to the available spatial and temporal data, can be a complex and quite difficult task. Since the focus is often more on developing a proof of concept than to approximate the absolute truth, there are certainly many uncertainties in the finally used knowledge rules. When further implementation is required, a debate is needed as to what extent absolute numbers can be used and when a more relative approach could be sufficient.

What types of value can the approach help me understand?

Quickscan combined the benefits of a quantified, spatial approach with a deliberative, stakeholder process. It can be used to explore most categories of value (biophysical, monetary, socio-cultural as well as aspects related to the intrinsic value of nature). What values are explored will depend on the individuals involved and the priorities of the case study.

How does the approach address uncertainty?

Uncertainty can be expressed explicitly within the rules used if needed. Often uncertainty is addressed within a rule showing different options for classification (e.g. the upper and lower sustainability boundaries of an indicator). Where and how this uncertainty is dispersed can then be assess spatially under different alternatives, as well as summarised as the total potential uncertainty in the region of interest.

How do I apply the approach?

The QUICKScan software encompasses a modelling environment that needs to be filled with spatial and/or statistical data during the preparation phase. The tool is not restricted to a specific geographic location or spatial resolution. Knowledge rules, capturing participant knowledge, are used to combine data and derive indicators. Typically the rules use classifications to describe quantitative data and typologies to give qualitative data meaning. Rules may be linked together to form a chain of rules. Alternative (chains of) rules are used to capture different options. Derived data from alternatives can be aggregated (e.g. by administrative units or biophysical units, such as catchments or climatic zones) to be displayed in tables and charts for overviews.

Figure 2 shows the different phases which are generally formulated using QUICKScan in a participative setting: (i) scoping; (ii) preparation; (iii) the workshop(s); and (iv) reporting. The scoping in the first phase is intended to identify and formulate key questions together with the stakeholders (Figure 2). The second phase is needed to prepare the spatial datasets to be used in the workshop. The third phase is the workshop itself which focuses on creating a common understanding about the key questions, their options and alternatives. To ensure good outputs and ease participation in this phase, the chained rules are often first defined in a simplified way, and then refined in iterations based on results and stakeholder needs. New iterations are also often used to incorporate new insight and demands. If needed, a summarising report in the form of a PowerPoint or a Document is produced describing the results from the workshop and the prior phases (Figure 2).

Below is an example of how an exploratory two day workshop could be organised and carried out:

A) Before the workshop:
   - Define the program around a policy question.
   - Search, obtain and organise the data needed.

B) At the workshop: example agenda

Day 1 Morning (9:30 - 12:30)

- *Define storylines.*
- *Determine how to measure the impact (key outputs/key indicators).*

Day 1 Afternoon (14:00 - 18:00)

- *Build workflow for policy alternatives*
- *Relate alternatives and key output to data.*

Day 2 Morning (9:30 - 12:00)

- *Present results, discuss and iterate.*
- *Define next steps and needs.*

C) After the workshop:

- Produce the report.
  Send report to stakeholders and iterate if needed to take account of feedback and additional demands.
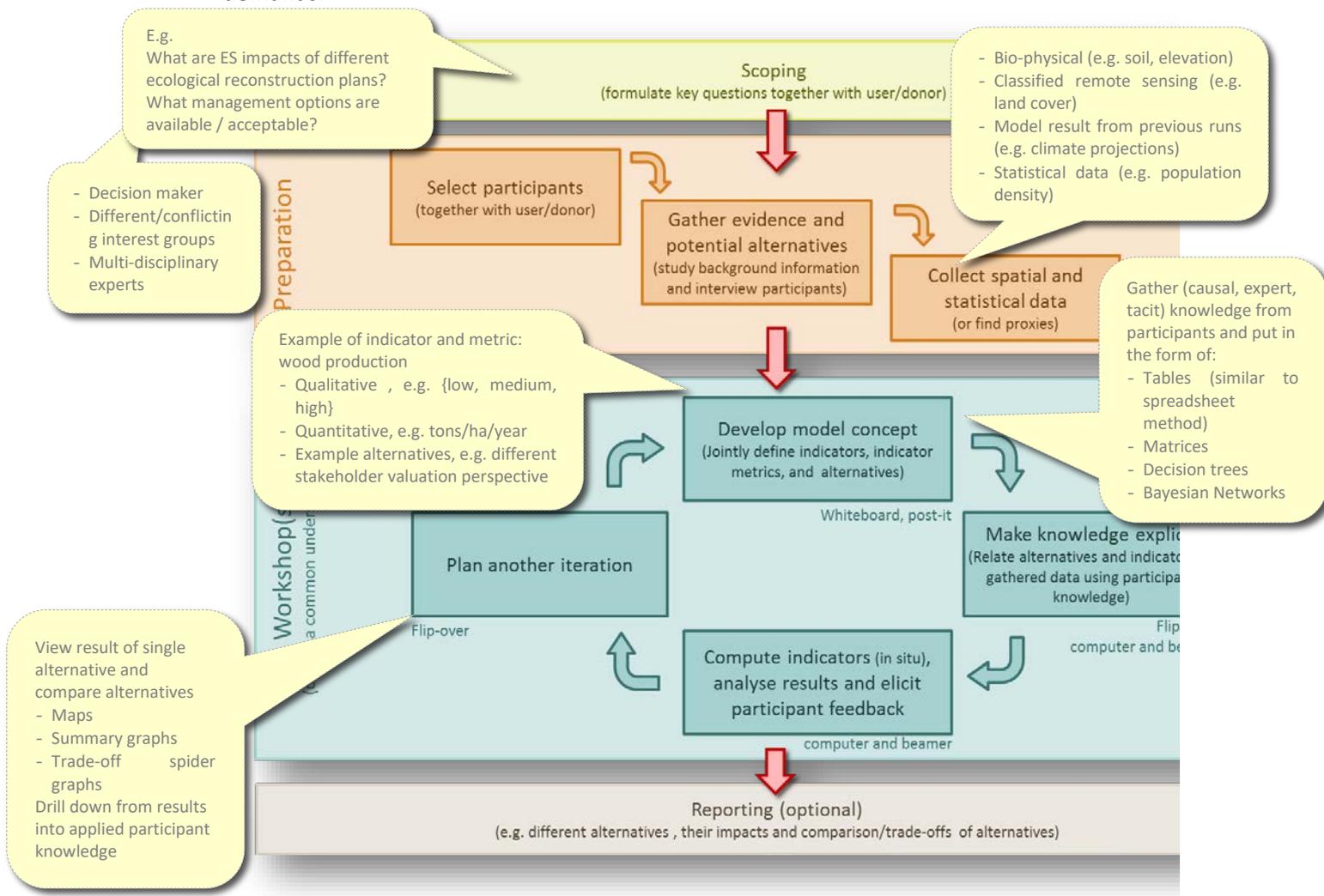

Figure 2: The different phases in the QUICKScan process.

In summary, it can be said that organising one or more workshops with stakeholders is the essential part of implementing a successful QUICKScan method. Figure 3 provides a summary of

the three elements that are crucial to run a successful QUICKScan workshop: people, process, and technology.
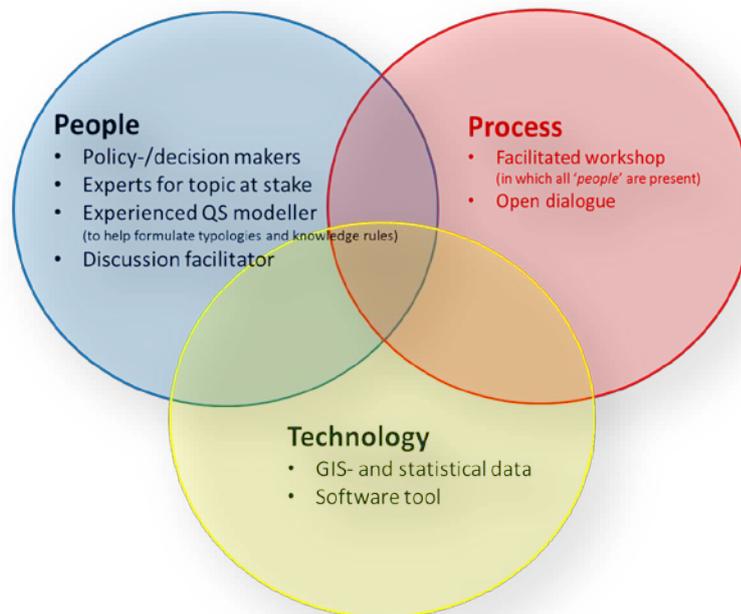
Figure 3: Overview what is needed to organise a QUICKScan workshop.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	The QUICKScan software encompasses a modelling environment that needs to be filled with spatial and/or statistical data during the preparation phase. Depending on the topic case study data is either already available in the QUICKScan tool (e.g. EU level, ES) or it needs to be prepared spcifically for the workshop. The tool is not restricted to a specific geographic location or spatial resolution.
Type of data	☑ Qualitative ☑ Quantitative	Both can be used. Typically the rules use classifications to describe quantitative data and typologies to give qualitative data meaning. Derived data can be aggregated to be displayed in tables and charts for overviews.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	QUICKSCan is (and thus can be) used in all three different mentioned settings, depending on the focus of the workshop. QuickScan is appropriate for targeted users: Multilateral, regional, national and local decision-makers; Multilateral, regional, national and local policy desk officers and project managers; Scientific experts and thematic researchers;

		NGOs staff, corporates staff, government officers. QuickScan can be targeted for: Participatory settings/workshops; Policy settings/explorations/assessments; Scientific baselines/iterations/validations; Ex-ante/ex-post impact assessments.
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	Two versions exist: 1. Community-edition: Light-weight latest version with up to 10 user defined rules. No support provided. 2. Ultimate edition: Full featured, latest stable version with an installation set, a user manual, support and free upgrades for a year. Software licence is required.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	QUICKScan usually requires some days of data preparation and one or two days for the workshop itself. Usually from start to finish it requires less than a month of lead time.
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	Usually two or three persons are involved in both the preparation phase and the workshop itself, requiring less than one person month in total.
Other requirements		

Where do I go for more information?

For further reading and references see the QUICKScan website: http://quickscan.pro, which includes an overview of the most important QUICKScan reports and case studies. The following references are mentioned on the website (http://quickscan.pro/showcases.html):

EEA (2011), *Green infrastructure and territorial cohesion*, EEA technical report 18.

Eshitera, A. (2013), *Assessing Agricultural Land Carrying Capacity for Sustainable Livelihoods and Resettlement of Internally Displaced Persons in South Darfur*, MSc thesis, supervisors: Boerboom,L., Dopheide, M., Faculty of Geo-Information Science and Earth Observation of the University of Twent

Eupen M van, B. Pedroli, C Huang, X. Wang (2007), *Impact modelling of scenarios on vegetation and fauna in the Yellow River Delta*. Yellow River Delta Environmental Flow Study Sino-Dutch Study Programme Final Report 2007 YRCC, Yellow River Water Resources Protection Bureau, Alterra, Delft Hydraulics, Arcadis Euroconsult.

Roos-Klein Lankhorst, J., de Vries, S., Buijs, A. (2011) *Mapping landscape attractiveness, a GIS based landscape appreciation model for the Dutch countryside*, Exploring the visual landscape, Advances in physiognomic landscape research in the Netherlands, edited by Steffen Nijhuis,

Ron van Lammeren, Frank van der Hoeven (pp 147 – 161); Research in Urbanism Series (RiUS), Volume 2, ISSN 1875-0192 (print), ISSN 1879-8217 (online). http://rius.tudelft.nl/article/view/210/265

Losekoot, S. (2013), *The Landscape appreciation model: construction and evaluation of two prototypes*, Technical report, Van Hall-Larenstein – wildlife management, Leeuwarden

Verweij, P. van Eupen, M., Roos-Klein Lankhorst, J., Nieuwenhuizen, W. (2010), *Qualitative reasoning in participatory spatial planning: the use of OSIRIS in the Yellow River Delta*, in: International Environmental Modelling and Software Society (iEMSs) 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada; David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.) www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Verweij, P., Winograd, M., Perez-Soba, M., Knapen, R., van Randen, Y. (2012), *QUICKScan: a pragmatic approach to decision support*, In: International Environmental Modelling and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.) www.iemss.org/society/index.php/iemss-2012-proceedings

Xingong Wang, Yu Lian, Chong Huang, Xiaojun Wang, Ruiling Wang, Kai Shan, Bas Pedroli, Michiel Eupen, Amgad ElMahdi, Mahtab Ali (2012). Environmental flows and its evaluation of restoration effect based on LEDESS model in Yellow River Delta wetlands. *Mitigation and Adaptation Strategies for Global Change*, 17(4): 357.

Factsheet prepared by Peter Verweij, Michiel van Eupen, Anouk Cormont, Marta Perez-Soba & Manuel Winograd

METHOD FACTSHEET

ECOPLAN-QUICKScan

Introduction

The ECOPLAN-QUICKScan tool is a script/method that is useful to make results from mapping and simulations insightful to stakeholders.

Keywords

Stakeholder inclusion; Spatially explicit tool; Simulation/ future analysis

Why would I chose this approach?

The tool converts spatial datasets on ES supply (e.g. maps of carbon stored) into a set of average values per unit area (e.g. carbon stored per hectare for each region). This allows different regions or scenarios to be compared. The target audience is local experts in, for example, spatial planning, environment or industry. The tool can help project planners with vision building and/or raising awareness on ES supply.

What are the main advantages of the approach?

- Comparing areas provides insight into the characteristics of a region relative to its surroundings and/or comparable sites/catchments;
- Comparing scenarios for a defined area reveals clearly the total aggregated impact of each scenario on ES delivery;
- Requires limited effort by the end user: the end user selects specific areas and /or scenario simulation results from a drop-down menu in a table;
- Results are made available in tabular form and graphs.

What are the constraints/limitations of the approach?

- Requires some VBA and Excel programming to adapt the tables and infographics to a new dataset;
- Reliant on availability of input data.

### What types of value can the approach help me understand?

The approach allows biophysical values to be mapped and explored with stakeholders. It also allows different future options to be explored. As such it can also be used to understand a wide range of socio-cultural and other values as part of the stakeholder process.

How does the approach address uncertainty?

Uncertainty can be explored by comparing values for alternative scenarios (e.g. by comparing high and low estimates of the same service. Services can be expressed in biophysical units or converted to monetary values.

How do I apply the approach?

ECOPLAN-QUICKScan is a technical tool to process mapping and modelling results to generate insightful data for specific areas. The input is GIS mapped raster datasets on ES-stocks or ES-delivery for a current situation and/or simulation results for (multiple) scenarios. Units can be quantitative or monetary, but they need to be specified as a value per unit area. A set of polygons is also needed that defines the specific areas of interest (specific sites, municipalities, provinces, catchments etc.). Map layers in GIS representing supply or delivery of different ES are selected with the aid of a Python script, then zones of interest are clipped and data for each zone is summarised. This procedure is also undertaken for land-use/land-cover data to make results area-independent for comparison. The totals are written to a text file that can be further processed in Excel. Examples of the output for a comparison of the value of ES between two sites are shown in Figure 1.
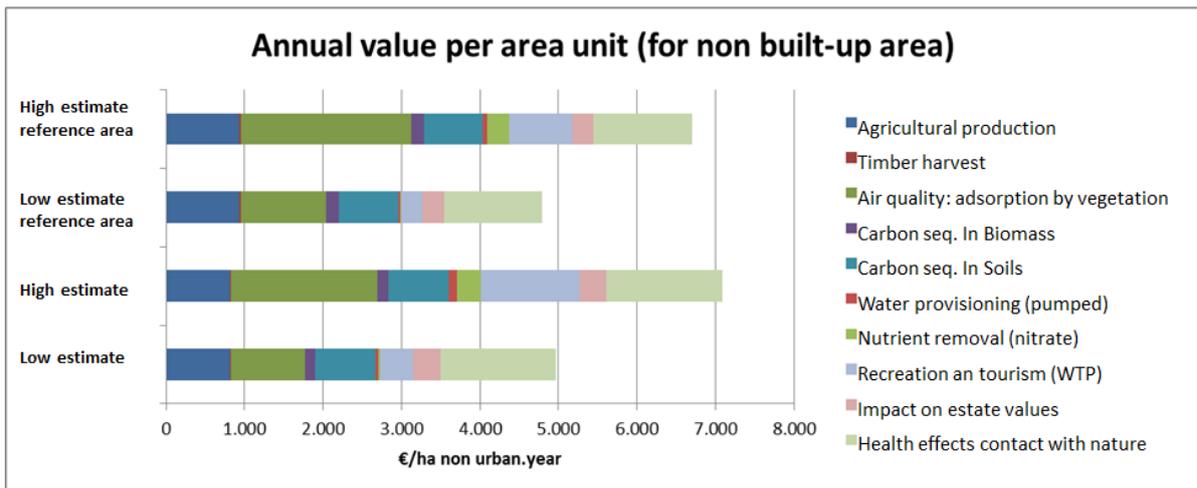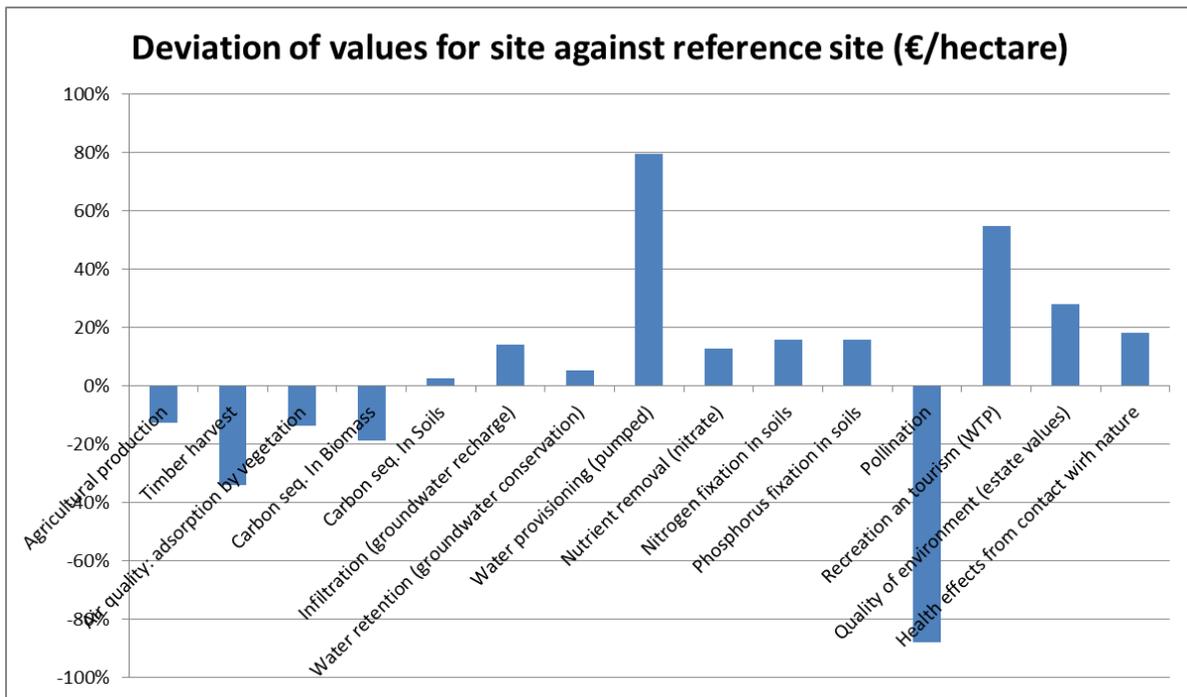
Figure 1: Illustrative outputs for ECOPLAN-QUICKScan.

Requirements

Data	☐ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	Depending on the case study, large amounts of data may need to be collected
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	The outputs are designed for discussion with stakeholders and to facilitate comparisons between regions
Software	☑ Freely available ☐ Software licence required ☑ Advanced software knowledge required	The software is coded to run in QGIS. Post-processing scripts need to be run to prepare data for QUICKScan. Software will become freely available by the end of next year.

Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	The ECOPLAN-QUICKScan system is composed of FOS scripts that run in Q-GIS, so any developer can take them and edit them. The current system is designed to work with Flemish Data, but with programming skills they can be made applicable for other data sets
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

Where do I go for more information?

Broekx, S., De Nocker, L., Liekens, I., Poelmans, L., Staes, J., Van der Biest, K., Meire, P. and Verheyen, K. (2013) *Estimate of the benefits delivered by the Flemish Natura 2000 network*. Study carried out on the authority of the Agency for Nature and Forests (ANB/IHD/11/03) by VITO, Universiteit Antwerpen and Universiteit Gent 2013/RMA/R/87 (March 2013). Online at https://www.uantwerpen.be/en/rg/ecoplan/research/products/

Factsheet prepared by Jan Staes & Francis Turkelboom

InVEST

Introduction

InVEST is a set of models for mapping and valuing the ecological or economic value of multiple ES at a local to regional scale. InVEST has a tiered design, from a simple Tier 0 to Tier 1 and 2 models, and is constantly under development. In recent years it has evolved from mapping only ES supply to also incorporate ES demand for some services. InVEST requires a land use map and spatial and non-spatial data associated to land use types.

In general Tier 0 models map relative levels of ES and thus highlight regions where particular services are in high supply or demand. Tier 1 models are theoretically grounded but simple. They are suitable when more data are available than are required for Tier 0, but they still have relatively simple data requirements. More complex Tier 2 models are under development for biodiversity and some ES. Currently, InVEST covers levels 0 and 1 in terms of complexity.

InVEST can be downloaded for free and most of the models run on a stand-alone platform, not directly connected to ArcGIS. Since the InVEST model is fully documented (see section on further reading), we do not aim to repeat this here. Instead, we only introduce the InVEST model as a potential and interesting tool for mapping single or multiple ES within the OpenNESS case studies.

InVEST currently includes 16 models that analyse different aspects of marine and terrestrial environments:

- **Aesthetic quality**: Maps the visibility of features on a seascape or landscape.
- **Biodiversity**: Characterizes habitat quality and quantifies relative habitat loss.
- **Carbon**: Quantifies and values carbon storage and sequestration in terrestrial ecosystems.
- **Coastal protection**: Quantifies and values the benefits of nearshore habitats for coastal protection.
- **Coastal vulnerability**: Assesses the relative risk to coastal areas from storms.
- **Crop pollination**: Quantifies and values the contribution of wild pollinators to agricultural production.
- **Habitat risk assessment**: Evaluates the risk to marine or terrestrial habitats from anthropogenic factors.
- **Managed timber production**: Values timber harvest.
- **Marine fish aquaculture**: Estimates the harvest weight and value of farmed salmon.
- **Marine water quality**: Models concentration of pollutants at sea.
- **Offshore wind energy**: Measures the electricity generation potential of wind over ocean and large lake surfaces.
- **Recreation**: Maps recreational use across a landscape and predicts future recreational use under alternative scenarios.

- **Reservoir hydropower production** (water yield): Quantifies water yield in a catchment and the amount and value of hydropower produced by a reservoir.
- **Sediment retention**: Quantifies soil loss and retention and values the avoided cost of water treatment or dredging.
- **Water purification**: Quantifies nutrient retention, and values the avoided cost of water treatment.
- **Wave energy**: Models and values harvested energy from wave power facilities.
- **Overlap analysis**: Identifies areas of potential conflict between various human uses.

Keywords

Multiple ecosystem service supply; Mapping; Valuation; Multiple scales; Process models.

Why would I chose this approach?

The power of InVEST lies mainly in the capacity to map multiple ES which enable users to do a trade-off assessment of certain land use or management scenarios (Goldstein et al., 2012). The InVEST platform provides associated tools such as the scenario generator that allows creating different land use scenarios to compare ecosystem services under these scenarios. Case studies can also map and model single ES. The carbon module, for instance, is frequently used as a model to map carbon stocks at local and regional levels.

What are the main advantages of the approach?

- The Natural Capital Project (http://www.naturalcapitalproject.org/index-2015.html) provides a standalone version of the tool, so there is no need for ArcGIS; any GIS software can be used;
- A complete set of tools is available, and a wide community of users is active around the world, all information is available here: http://www.naturalcapitalproject.org/models/models.html;
- It allows modelling of ES using multiple datasets, thus results are presumably more accurate than single-indicator based ES maps;
- It is possible to compare ES under different land use scenarios.

What are the constraints/limitations of the approach?

- Previous versions of InVEST were provided as a toolbox to ArcInfo from ESRI but the latest version is a stand-alone version;
- Typically, working with InVEST requires a good command of GIS and good knowledge of spatial data formats;
- Data preparation needs vary with the individual sub-models. Some such as climate regulation are not intensive in terms of data needs, however, data preparation for other ES can be quite long and demanding. A good knowledge of spatial data formats is needed;
- The user can not verify and control the intermediate steps of the models.

What types of value can the approach help me understand?

InVEST is designed to provide both biophysical and monetary values for the ecosystem services it includes.

How does the approach address uncertainty?

Early versions of InVEST did not account for uncertainty. However, recent versions have incorporated uncertainty analysis. Uncertainty analysis with InVEST helps when there is lack of data (or when there is uncertainty associated with data) for some of the variables that are needed to run the different models. The outputs of the uncertainty analysis include confidence rasters and standard deviations.

How do I apply the approach?

An InVEST project would include the following steps:
1. Getting familiar with the models and data needs by reading the manual. It is available on the Natural Capital InVEST web page (http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/);
2. Deciding which ES to model;
3. Collecting, managing and handling the spatial data needed as input;
4. Running the models for current ES delivery/demand and/or for different land use scenarios;
5. Reporting and interpreting the results.

The suite of ES models within InVEST each require different understanding and implementation. These specific details are provided in the User Guide (see further reading).

An illustration of the application of InVEST is provided for the two Spanish case studies. In Sierra Nevada (CS10) and Doñana (CS19), InVEST has been used to model climate regulation (see Palomo et al., 2014 for details). Data requirements to run this model have been a land use map and the following variables associated with carbon storage: carbon storage in above and below ground biomass, soil organic matter, and dead organic matter. To run the model it was necessary to perform a literature review to gather the values of these variables for the different land use types that exist in the study areas assessed. Outputs are presented in tons of elemental carbon, but their economic value could be estimated as well. Figure 1 shows different ES mapped in the Doñana Case study. Climate regulation (as carbon storage) was mapped using InVEST while the others where mapped based on indicators or on other existing models.
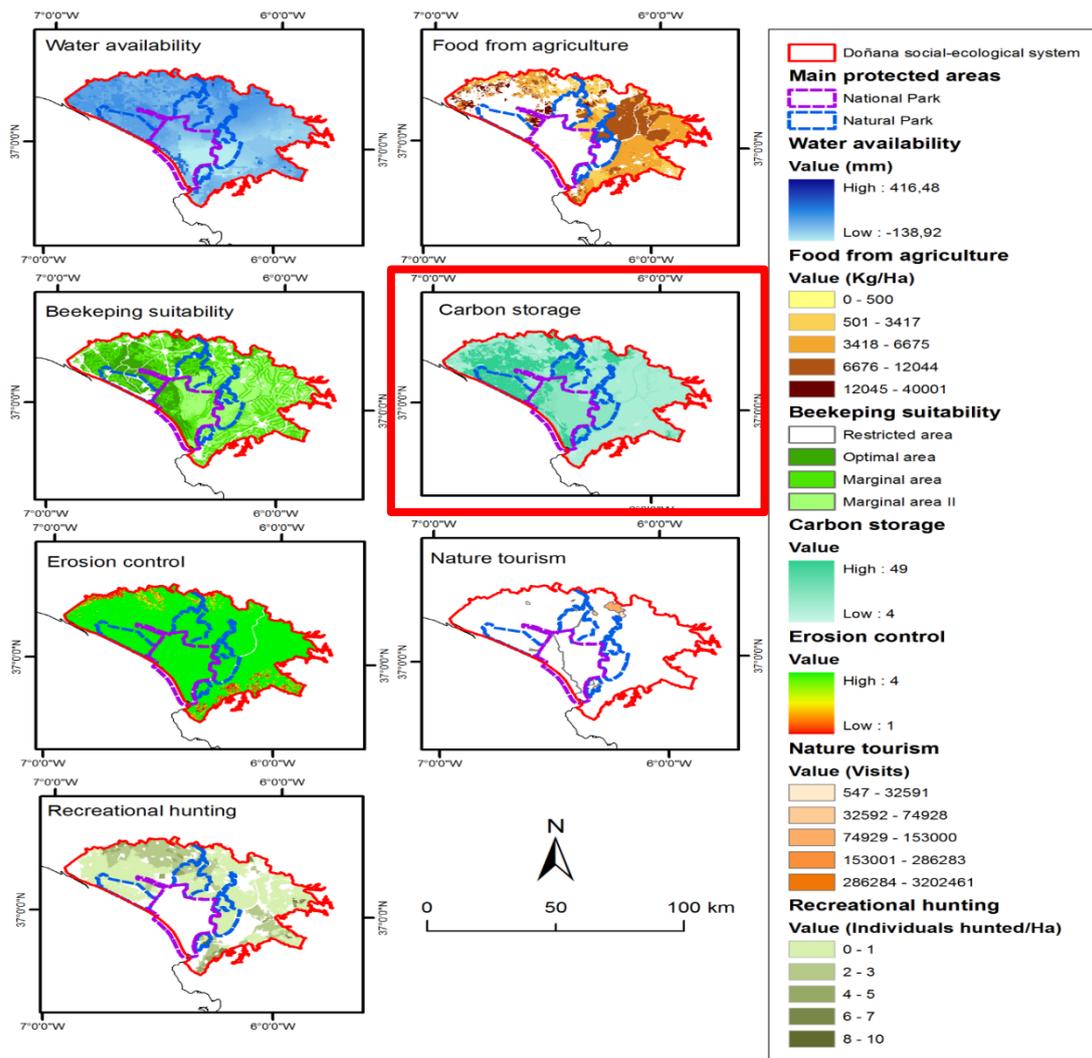
Figure 1: The different ES mapped in the Doñana Case study. InVEST was used for the carbon storage model (red box) which can then be compared with the other ES.

Requirements

Data	☐ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit data sets (vector or raster) and additional information such as the values for different different variables for the existing land use types in the study area.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	

Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	A stand-alone software is provided and is freely available
Time resources	☐ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources depend on the expertise of the researchers and GIS specialists and on the existing data. Case studies which use InVEST to quantify four to five ES should probably assume 3-5 person-months to set up a complete InVEST project.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	
Other requirements		

Where do I go for more information?

All information on InVEST is available here: http://www.naturalcapitalproject.org/
The software can be downloaded here: http://www.naturalcapitalproject.org/download.html
The user forum is an additional tool which provides information and real support about different topics and practical problems: http://ncp-yamato.stanford.edu/natcapforums/discussion/7/welcome-to-the-natural-capital-project-forums/p1

Goldstein, J. H., Caldarone, G., Duarte, T. K., Ennaanay, D., Hannahs, N., Mendoza, G., ... & Daily, G. C. (2012). Integrating ecosystem-service tradeoffs into land-use decisions. Proceedings of the National Academy of Sciences, 109(19), 7565-7570.

Natural Capital book. Theory and Practice of Mapping Ecosystem Services. Edited by Peter Kareiva, Heather Tallis, Taylor H. Ricketts, Gretchen C. Daily, and Stephen Polasky:

http://global.oup.com/academic/product/natural-capital-9780199588992?cc=it&lang=en&

Palomo, I., Martín-López, B., Alcorlo, P., & Montes, C. (2014). Limitations of Protected Areas Zoning in Mediterranean Cultural Landscapes Under the Ecosystem Services Approach. Ecosystems, 17(7), 1202-1215.

Factsheet prepared by Grazia Zulian & Ignacio Palomo

BIOPHYSICAL METHODS

MapNat smartphone application

Introduction

The MapNat tool is designed to be applied by citizens and scientists who are interested in mapping the use of mainly cultural, but also some provisional and regulating, services and disservices.

Keywords

Citizen science; Cultural ES; Smartphone application.

Why would I chose this approach?

Interest in mapping personal use of nature's resources or the requirement to support scientists and planners in generating information about the demands for a large number of ES and disservices perceived by users. It is an easy-to-use direct mapping tool, providing not only immediate feedback of the mapped services, but also access to the services mapped by other users. Thus, citizens are enabled to identify locations with ES of interest, whereas scientists or planners might be more interested in assessing the spatio-temporal pattern of ES demand.

What are the main advantages of the approach?

- The MapNat App only requires an ANDROID (v 4.XX) based smartphone with a GPS device;
- For installation of the App and for up- and downloading data and maps, internet access is needed;
- No knowledge on ES or their classification is required;
- Basic knowledge of English, if the App does not support their own language.
- MapNat App is easy to use;
- It is applicable by citizens and scientists;
- It has global applicability and comparability of results;
- Users can download or export the ES they map from their phones and display or evaluate them for their own purposes;
- Unlike many other smartphone apps MapNat does not collect any personal information, unless users decide to register voluntarily;
- The ES categories used in the app are compatible with the widely used CICES (V 4.3) list.

What are the constraints/limitations of the approach?

- The perspective for which the app is designed is to map ES demand (ES flow), i.e. of a citizen using one or multiple ES, or a scientist reporting the use of ES by the people he or she is observing;

- The thematic focus is on cultural services, and a couple of regulating and provisioning services which are considered to be relevant for direct use by citizens, such as using drinking water or fire wood.

What types of value can the approach help me understand?

The approach is especially good for identifying areas of socio-cultural value as mapped directly by citizens themselves. It can also contribute information on biophysical values at the level of where large blue-green areas are located.

How does the approach address uncertainty?

The method does not explicitly address uncertainty.

How do I apply the approach?

MapNat enables its users to map ES in three different ways as points, lines or areas on a map. Once the user selects a location, he/she is guided to a list to select the ES which is being used. Users can deliver additional information, e.g. about the vegetation, or provide comments or a photograph. Mapped uses are immediately visible on the map display, which also shows the records of all other users displayed in different colors, depending on the type of ES or disservice. Internet connection is not needed during use, but is required for up- and downloading data as well as refreshing the map display.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	
Type of data	☑ Qualitative ☐ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements	Smartphone needed (currently ANDROID)	

Where do I go for more information?

Priess J.A., Elger R. and Hauck J. 2014. The ESM-App – a new smartphone application to map ecosystem services. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), *Proceedings of the 7th International Congress on Environmental Modelling and Software,* June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2.

Factsheet prepared by Jörg Priess

Blue-green factor scoring

Introduction

Green space factors and points systems have been used in several European cities as a policy instrument to attain desired levels of green and blue surfaces in new property developments (Farrugia et al., 2013; Fongar, 2015; Kruuse, 2011; Szulczewskaa et al., 2014). Different green and blue 'elements' are scored based on their importance for a particular ES, or a bundle of services, and an area-weighted score is calculated for a proposed property development.

Keywords

Urban ES; Green infrastructure; Blue infrastructure; Smartphone application.

Why would I chose this approach?

The aim of blue-green factor (BGF) scoring is safeguarding blue-green structures and elevating the status of such structures within urban environments through awareness-raising. Green space factors are a non-economic valuation method because they score the relative importance of different green structures. They are also a policy instrument. The BGF may be used for certifying new building development in relation to achieving a minimum total score that can be differentiated for different parts of a city depending on demand for the ES in question. At the same time, property developers are given flexibility in designing how to incorporate blue-green structures into building plans. The BGF developed for Oslo municipality (OpenNESS case study 3) focuses on the urban flood control function of green and blue structures. Other green space factor scoring systems may weight structures differently based on other ES.
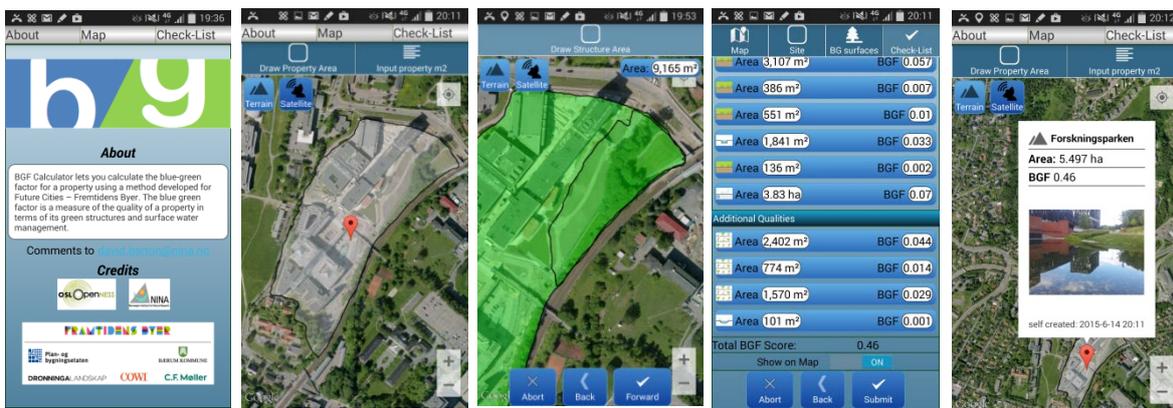
Figure 1: Selected screens from the BGF App for Android Smartphones.

A practical reason for using the approach is that there are few methods that evaluate ES supply at the spatial resolution of a property (rather than a pixel). The scoring system can be easily implemented using an Excel spreadsheet. An App for Android Smartphones has also been

developed that allows a property owner to carry out a rapid assessment of the BGF at property level (Figure 1). Pixel-based extrapolation of BGF scoring to whole catchments is being tested in Oslo.

What are the main advantages of the approach?

- Ease of use (Excel spreadsheet, Smartphone App);
- Speed of use;
- Draws on existing data;
- Participatory approach – can be applied by stakeholders themselves;
- Spatially-explicit;
- Expert knowledge not required for its use.

What are the constraints/limitations of the approach?

- Property-specific weighting;
- Weighting not adjusted for spatial context, such as catchment location, hydrological characteristics of neighbouring properties;
- BGF structures and weights have been selected and developed by an expert panel to specifically address urban flood control, with some additional weight being given to importance of biodiversity habitat. Weights should not be applied to other ES.

What types of value can the approach help me understand?

The tool can help identify socio-cultural values held by citizens as well as provide information on regulating ES provision as biophysical value.

How does the approach address uncertainty?

The approach does not explicitly address uncertainty.

How do I apply the approach?

Through the Cities of the Future program, Oslo Municipality Planning and Building Agency, Bærum Municipality, Dronninga Landskap AS, Cowi AS, and C. F. Møller collaborated in developing a 'blue-green factor' (BGF) scoring system to guide new urban development towards the overall goals of the Green Plan for Oslo (FramtidensByer, 2014). BGF was inspired by the Biotopflächenfaktor (Berlin), Grönytefaktor (Malmö) and Green area factor (Stockholm). The BGF proposal has been developed and tested on a number of case studies. However, the final proposal has so far not been incorporated into municipal building codes or regulation.

The BGF scores the 'importance' of each structure based on performance criteria mainly in relation to water infiltration and storage capacity. Scores are given for different kinds of blue-green surfaces in relation to their hydrological regulating effect. Additional points are then given for water and vegetation features that enhance run-off control in conjunction with aesthetic qualities and biodiversity habitat (Figure 2).
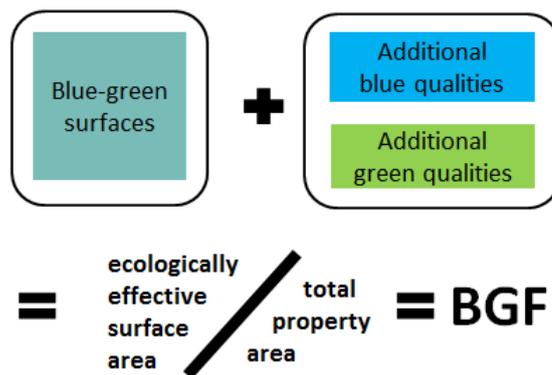
Figure 2: Blue-green factor calculation. Source: translated from Framtidens Byer (2014).

Each structure score is divided by the total plot area resulting in normalised BGF scores for each structure. The total score is calculated through either adding all individual BGF scores or dividing the total value scores by the total plot area. The sum of scores is divided by the total property area, so that each property has a normalised BGF score/m2 which can be compared across properties (Figure 3).   Scoring of each structure is based on the judgement of technical experts in architecture, urban planning, hydraulics and hydrology. Judgements were tested and adjusted through a number of case studies in Oslo (Framtidens Byer, 2014):

- **Blue-green surfaces**
  - Open permanent water surfaces are relatively more important than potentially permeable or impermeable surfaces with regard to their run-off storage capacity.
  - Vegetation surfaces with direct drainage to soil or bedrock are more important than surfaces with no drainage with regard to their infiltration potential. The deeper the soil for non-connected surfaces the higher the water storage capacity.   Non-connective surfaces refer to soils and vegetation placed above built structures, such as sub-terrain parking or green roofs.

- **Blue additional qualities**
  - Natural edges and rain beds slow water flow rates, and increase water basin holding capacity, in addition to providing aesthetic and habitat qualities to water surfaces.
- **Green additional qualities**
  - **Trees** are scored individually relative to size and growth potential, determining their importance for rainfall interception and evapotranspiration, and for their functions as habitat and for aesthetics. Trees may constitute a large share of the total BGF score for a property.
  - **Native vegetation, perennials and other ground cover** provide additional scores for their importance for biodiversity habitat and aesthetics.
  - **Hedges, bushes and green walls,** give additional scores for both their hydrological properties and their aesthetic value.
  - **Contiguous green areas and connection** give additional score for their importance as recreation areas and connectivity with other urban green infrastructure structure.

Value	Symbol	Factor
		Plot Area (including the built area) Fill out the area
		1.BLUE-GREEN SURFACES
1		Open permanent water surface that can receive rainwater
0.3		Partially permeable surface like gravel, crushed stone, and reinforced grass surface
0.2		Impermeable surfaces with drainage to vegetated areas or an open drainage magazine
0.1		Impermeable surfaces with drainage to a local closed storm water drainage
1		Surfaces with vegetation associated with soil or bedrock
0.8		Surfaces with vegetation, not associated with soil > 80 cm
0.6		Surfaces with vegetation, not associated with soil 40 – 80 cm
0.4		Surfaces with vegetation, not associated with soil 20 – 40 cm
0.2		Surfaces with vegetation, not associated with soil 5 –20 cm

Value	Symbol	2. Additional qualities = Blue and Green additional qualities that give extra points. The same area can therefore be counted a number of times below
		Blue additional qualities
0.3		Natural edges to water srufaces
0.3		Rain bed or equivalent
		Green additional qualities, Points below (trees) should be filled in as a number
1		Existing large trees > 10 m
0.8		Existing trees that can be expected to grow to over > 10 m
0.6		Existing trees that can be expected to grow to be small to medium, 5 – 10 m
0.7		Newly planted trees that are expected to be > 10 m
0.5		Newly planted trees that are expected to be 5 – 10 m
		Points below should be filled in as m2
0.6		Native vegetaion
0.4		Hedges, bushes and multi-stemmed trees
0.4		Green walls
0.3		Perinnials and other ground cover
0.1	75m2	Contiguous green areas over 75 m2
		Points below are filled in with the number 0,05
0.05		Connection to existing blue-green structures.
		TOTAL BLUEGREEN FACTOR (BGF)

Figure 3: Blue-green factor scores. Source: translated from Framtidens Byer (2014).

The assessment approach recognises that ES of green infrastructure are 'bundled', and difficult to disentangle. The BGF therefore has a deliberate focus on regulating hydrological services in order to be simple to implement. For this reason structures providing biodiversity habitat, aesthetics and recreation are seen as 'additional' ES. Their relative importance in the overall BGF score is also smaller than for the hydrological regulating services.

The BGF focus on simplicity means that each structure is scored the same no matter where the assessment takes place. The assumption is that the marginal value of each structure in terms of surface area or number of individual trees is the same whether upstream or downstream in an urban catchment. BGF scoring also does not presently differentiate between developed (landscaped) and natural properties with high density of trees.

Requirements

Data	☐ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Area calculations for blue and green structures can be calculated using the BGF App.
Type of data	☑ Qualitative ☑ Quantitative	Weighting (predetermined scores) Surface areas and counts
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields ☐ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	Excel spreadsheet (upon request) Android Smartphone App (upon request)
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Smartphone-based assessment of a single property can be carried out in about 1 hour.
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

Where do I go for more information?

Guidance document in Norwegian can be downloaded here:

Fremtidens Byer (2014)

http://www.miljodirektoratet.no/Global/klimatilpasning/Bl%C3%A5gr%C3%B8nn%20faktor/BGF%20Veileder%20byggesak%20Hoveddelen%202014.01.28.pdf

An extensive explanation can be found in Fongar (2015) (to be made available at the OSLOpenNESS case website http://www.openness-project.eu/node/78)

Fongar, C., 2015. Identification of bluegreen structures and percieved values in public urban green spaces: a comparative case study of a natural and a constructed green space in Oslo, Master of Science in Natural Resources Management. Specialization Geography. Norwegian University of Science and Technology, Faculty of Natural Science and Technology, Department of Geography, p. 127.

Kruuse, A., 2011. The green space factor and the green points system. GRaBS Expert Paper 6 (Green and Blue Space Adaptation for Urban Areas and Eco Towns).

Szulczewskaa, B., Giedycha, R., Borowskib, J., Kuchcikc, M., Sikorskib, S., Mazurkiewiczd, A., Sta´nczykea, T., 2014. How much green is needed for a vital neighbourhood? In search forempirical evidence. Land Use Policy 38, 330– 345.

Simple Matrix Approach

Introduction

Matrix Approaches are a quick and simple way to get an overall spatially-explicit picture of the ES in case study areas. The method is based on the idea of linking tabular spreadsheet data and spatial data together, i.e. joining external datasets to spatial units to create maps. The spreadsheet format data can be collected, for example, as expert evaluation or constructed from indicators or statistics. Simple application of the approach typically involves land use or land cover (LULC) datasets, although other datasets can be used.

This document is designed to introduce you to the ***basics of the matrix approach***. There is a separate factsheet is available on an *"Advanced Matrix Approach"* that you may wish to read as a follow on to this factsheet**.** The advanced version of the matrix method has been suggested to improve representation of the transdisciplinary issues that are often related with ES studies (e.g. including advanced sources of knowledge, encouraging collaboration amongst stakeholders). It utilises an extensive set of spatial datasets grouped into themes (instead of using solely LULC data) combined with both scientific experts' and local actors' scorings. The method was developed to assess spatial variation in ES provision potential of green infrastructure in spatial planning.

Keywords

GIS; Ecosystem services; Spreadsheets; Matrix; Expert scoring; Stakeholder engagement; Semi-quantitative methods.

Why would I chose this approach?

Simple matrix approaches are great as a means to:

1) To get a quick overview of the potential supply of, demand for and budgets of ecosystem services.
Burkhard et al. (2012) used spreadsheets for creating a scored ES reclassification table (also often called an expert knowledge table) which was coupled with the CORINE Land cover (CLC) database to produce ES supply, demand and budgets maps. By linking expert evaluation of the ability of each LULC class to supply ES as well as the demand for various ES within the same LULC classes, overview maps of both supply and demand were quickly derived. When supply and demand were calculated together, budgets were created.

2) To detect possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist.
A spatially-explicit ES mapping exercise can be used for detecting possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist (e.g. Vihervaara et al. 2010;

2012). In addition, optimising multiple ES and conservation needs is possible. Potentially relevant biodiversity datasets include for example EUNIS (e.g. Natura 2000 habitats), agricultural parcels (e.g. grasslands, pastures) and multi-source forest inventories. In general, ES assessments can be extended by using additional datasets related to land cover types, such as statistics (e.g. Kandziora et al. 2013), modelled data (e.g. Nedkov & Burkhard 2012) or monitoring data (Baral et al. 2013).

What are the main advantages of the approach?

- Relatively easy and fast to perform;
- Draws on existing data, can handle missing data, and expert knowledge can be included;
- Basic knowledge of spreadsheets and GIS is usually enough;
- Open source software can be used;
- Simultaneous assessment of multiple ES;
- Applicable at different scales: best possible datasets of appropriate resolution need to be used accordingly;
- Naturally an integrative / holistic approach;
- Suitable for transdisciplinary research problems;
- Easily adoptable, transparent and flexible.

NB Consider *Advanced Matrix Approaches* (separate fact sheet) for the following additional advantages:
- Useful in a participatory approach with stakeholders;
- Takes also into account features that reduce the provision potential;

What are the constraints/limitations of the approach?

- Availability of the background data might be a restraint;
- If a matrix using LULC data is applied, the data might be too coarse to study small case study areas;
- Data preparation can be quite a long and demanding task when a wide array of spatial datasets is used (GreenFrame);
- Possibly biased answers by the experts;
- Reliability of the results should always be evaluated;
- Wide matrices can be quite exhausting to fill in with scores and loss of concentration can result in errors in scores.

What types of value can the approach help me understand?

The approach can be used for both the supply and demand of ecosystem services. It can provide outputs across all ecosystem service types and represent both biophysical and socio-cultural values. It is not designed to provide information on monetary values.

How does the approach address uncertainty?

Spreadsheet-type methods do not generally address uncertainty explicitly.

How do I apply the approach?

The following steps need to be undertaken to apply the spreadsheet-type method within a case study:

Step 1: Gather relevant spatial datasets on land use, land cover type, habitats, biodiversity, etc. in GIS format. The most commonly used GIS data on LULC for Europe is CORINE which is readily available. However, other relevant spatial datasets can also be used, but it is important to evaluate their accuracy. It is also important to ensure that spatial datasets of an appropriate resolution are used for the spatial scale of the case study. The LULC or other classes in these datasets form the basis for the spatial interpolation of the spreadsheet data.

Step 2: Create a fit for purpose spreadsheet arrangement following the LULC classes and the selected ES (see Figure 1 below) where the first column contains the names of the CORINE land cover classes). The ES to be assessed are usually listed in the columns and the LULC classes in rows. A column with identical numbers for LULC classes helps to link the matrix information to the GIS data.

Figure 1. An example spreadsheet matrix of ecosystem services and land cover classes

scale for assessing capacities:

- 0 = no relevant capacity
- 1 = low relevant capacity
- 2 = relevant capacity
- 3 = medium relevant capaci
- 4 = high relevant capacity
- 5 = very high relevant capac

Step 3: Test your matrix with expert colleagues to find out any possible errors that might occur.

Step 4: Collect expert evaluation scores within spreadsheet tables based on questionnaire surveys, interviews or workshops. Whatever method is used to collect the evaluation score, it is crucial that the respondents are carefully selected to represent the case study area and issue. Unambiguous definitions for each ES and other unclear terminology should be provided to all the experts to ensure they have the same understanding of how to fill the table. Scores are derived from an expert evaluation based on the expected ability of all LULC classes to supply ES and in a separate sheet the demand for such services within current LULC classes. Simple calculation rules are applied between the columns.

Step 5: Collect all the scores from different respondents in one file and derive the median or mean value per LULC class and ES. Save the scores to a database file (*.dbf) or Excel format (.xls).
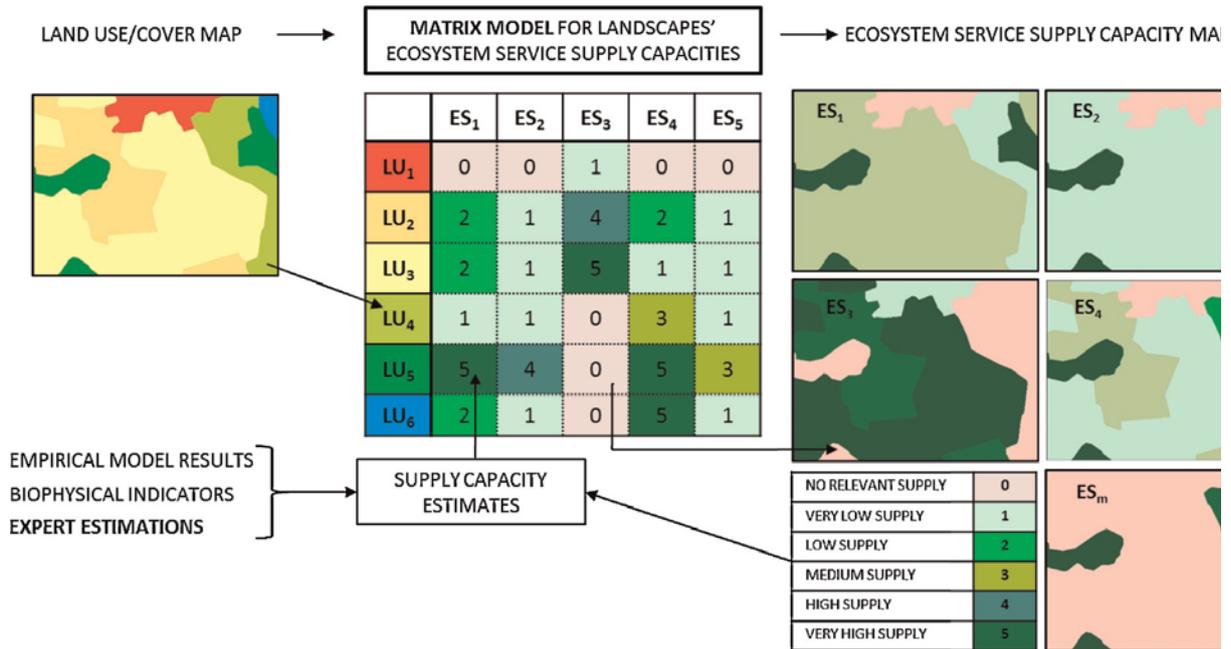
Figure 2. Spatial representation of ES provision using the Matrix model

Step 6: Import the data from the spreadsheet to a GIS programme to illustrate the results in a map (see figure 2). Joining the imported table to the spatial datasets enables a spatial representation of ES provision to be generated. It is possible to open Excel tables directly in common GIS software, such as ArcGIS, and work with them in the same way as other tabular data sources. For example, you can add them to ArcMap, preview them in ArcCatalog, and use them as inputs to Geoprocessing tools. Simple assessments can be undertaken with basic overlaying techniques (e.g. Geoprocessing Tools, Raster Calculator and Overlay Tools in ArcGIS). Maps can be finalized in Layout View.

Step 7: Evaluate the relevance and uncertainties of the results. It is also useful to elaborate them with the experts in a second workshop. Comparisons can also be made with similar case studies.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	The need to collect new data depends on: (i) the objectives of the case study; (ii) the matrix-type method selected (based solely on LULC or based on a wide variety of spatial datasets as in GreenFrame method); and (iii) on the availability of data from the case study area.
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit datasets (vector or raster) and additional information are needed.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Basic knowledge in spreadsheets and GIS are needed to conduct the assessment successfully. Facilitating expert evaluations and focus groups needs social and stakeholder engagement skills as well as the ability to clarify the ES concept, ES categories, the content and quality of various spatial datasets, and the scoring task in an understandable and uniform way.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	Any general spreadsheet software (e.g. Excel, Lotus123, Google Spreadsheets) is suitable to collect data in tabular form. Before the data is imported into a GIS programme, the data must be saved to a database IV file (*.dbf) or Excel format (*.xls). The method can be applied using any type of GIS software, licensed (ArcGIS) or open source (GRASS, QGIS, R, etc.). The LULC data should be in Shapefile format (*.shp) or a raster image (e.g. *.tiff, *.img), with LULC coding. The GIS software is needed to join the tabular data to the spatial data for the spatial analysis and creating output maps.
Time resources	☑ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources depend on the availability and accessibility of spatial datasets, on the need for pre-preparing the datasets for analysis, and on the expertise of the researchers and GIS specialists.
Economic resources	☑ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Similar to time resources.
Other requirements	When using GreenFrame, expertise is needed in carrying out focus groups and working together with researchers from other fields as well as with local and regional actors. Basic knowledge of statistics is also needed (understanding variation, mean, median, etc.).	

Where do I go for more information?

Burkhard, B., Kandziora, M., Hou, Y. and F. Müller (2014), 'Ecosystem service potentials, flows and demands–concepts for spatial localization, indication and quantification'. Landscape Online, 34, 1-32.

Burkhard, B., Kroll, F., Nedkov, S. and F. Müller (2012), 'Mapping ecosystem service supply, demand and budgets', Ecological Indicators, 21, 17-29.

Kopperoinen, L., Itkonen, P. and J. Niemelä (2014), 'Using expert knowledge in combining green infrastructure and ecosystem services in land use planning: an insight into a new place-based methodology'. Landscape Ecology, 29 (8), 1361-1375.

Vihervaara, P., Kumpula, T., Ruokolainen, A., Tanskanen, A. & B. Burkhard (2012), 'The use of detailed biotope data for linking biodiversity with ecosystem services in Finland', International Journal of Biodiversity Science, Ecosystem Services & Management, 8 (1-2), 169-185.

Vihervaara, P., Kumpula, T., Tanskanen, A. and B. Burkhard (2010), 'Ecosystem services – A tool for sustainable management of human-environment systems. Case study Finnish Forest Lapland', Ecological Complexity, 7, 410-420.

Prepared by Leena Kopperoinen & Laura Mononen

METHOD FACTSHEET

Advanced Matrix Approach (GREENFRAME)

Introduction

Matrix Approaches are quick and simple ways to get an overall spatially-explicit picture of the ES in case study areas. The method is based on the idea of linking tabular spreadsheet data and spatial data together, i.e. joining external datasets to spatial units to create maps. The spreadsheet format data can be collected, for example, as expert evaluation or constructed from indicators or statistics. Simple application of the approach typically involves land use or land cover (LULC) datasets, although other datasets can be used.

An advanced version of the matrix method has been suggested to improve representation of the transdisciplinary issues that are often related with ES studies (Jacobs et al. 2015). A modified, transdisciplinary version of the spreadsheet-type method is GreenFrame, which uses an extensive set of spatial datasets grouped into themes (instead of using solely LULC data) combined with both scientific experts' and local actors' scorings (Kopperoinen et al. 2014). The method was developed to assess spatial variation in ES provision potential of green infrastructure in spatial planning.

This document details the ***Advanced Matrix Approach***. To get an understanding of the methodology on which this builds it may help to read the "*Simple Matrix Approach*" factsheet prior to this.

Keywords

GIS, ecosystem services, spreadsheets, matrix, expert scoring, stakeholder engagement, semi-quantitative methods.

Why would I chose this approach?

The advanced matrix approach adds two additional advantages to the main advantages of the simple approach. The advantages of the simple matrix approach are:

1) To get a quick overview of the potential supply of, demand for and budgets of ecosystem services.
Burkhard et al. (2012) used spreadsheets for creating a scored ES reclassification table (also often called an expert knowledge table) which was coupled with the CORINE Land cover (CLC) database to produce ES supply, demand and budgets maps. By linking expert evaluation of the ability of each LULC class to supply ES as well as the demand for various ES within the same LULC classes, overview maps of both supply and demand were quickly derived. When supply and demand were calculated together, budgets were created.

2) To detect possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist.

A spatially-explicit ES mapping exercise can be used for detecting possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist (e.g. Vihervaara et al. 2010; 2012). In addition, optimising multiple ES and conservation needs is possible. Potentially relevant biodiversity datasets include for example EUNIS (e.g. Natura 2000 habitats), agricultural parcels (e.g. grasslands, pastures) and multi-source forest inventories. In general, ES assessments can be extended by using additional datasets related to land cover types, such as statistics (e.g. Kandziora et al. 2013), modelled data (e.g. Nedkov & Burkhard 2012) or monitoring data (Baral et al. 2013).

The advanced matrix approach brings the following additional advantages:

3) To help spatial planning in assessing green infrastructure based on ES supply and demand.

By using GreenFrame it is possible to get a more comprehensive map of the spatial variation in ES provision potential of green infrastructure. This helps to identify the key areas of green infrastructure in spatial planning (see procedure in Itkonen et al. 2015). Coupled with spatial assessment of potential and actual ES demand, as well as the connectivity of green infrastructure, spatial planners obtain valuable information on what type of ecological and social values are attached to different areas and are better informed for making decisions of land allocation for different purposes.

4) To engage stakeholders and local and regional actors in decision-making, to enhance joint understanding and to raise awareness of the various benefits that nature provides to us.

GreenFrame, which involves focus groups and the active involvement of local and regional stakeholders, raises awareness of the benefits of the ES approach. To enable the scoring of different data themes based on whether they are likely to positively or negatively affect ES provision potential, the concept of ES, content of the spatial datasets and the principles of scoring must be presented and explained in detail. In addition, by bringing stakeholders (local and regional actors) around the same table for discussion, different viewpoints are shared and common understanding is usually enhanced. The process itself can be as important as the maps resulting from the analyses when applying GreenFrame.

What are the main advantages of the approach?

- Relatively easy and fast to perform;
- Draws on existing data, can handle missing data, and expert knowledge can be included;
- Basic knowledge of spreadsheets and GIS is usually enough;
- **(Advanced) Takes also into account features that reduce the provision potential;**
- Open source software can be used;
- Simultaneous assessment of multiple ES;
- Applicable at different scales: best possible datasets of appropriate resolution need to be used accordingly;
- Naturally an integrative / holistic approach;
- Suitable for transdisciplinary research problems;
- **(Advanced) Useful in a participatory approach with stakeholders;**

- Easily adoptable, transparent and flexible.

What are the constraints/limitations of the approach?

- Availability of the background data might be a restraint;
- If a matrix using LULC data is applied, the data might be too coarse to study small case study areas;
- Data preparation can be quite a long and demanding task when a wide array of spatial datasets is used (GreenFrame);
- Possibly biased answers by the experts;
- Reliability of the results should always be evaluated;
- Wide matrices can be quite exhausting to fill in with scores and loss of concentration can result in errors in scores.

What types of value can the approach help me understand?

The approach can be used for both the supply and demand of ecosystem services. It can provide outputs across all ecosystem service types and represent both biophysical and socio-cultural values. It is not designed to provide information on monetary values.

How does the approach address uncertainty?

Spreadsheet-type methods do not generally address uncertainty explicitly.

How do I apply the approach?

The following steps need to be undertaken to apply the Advanced Matrix method within a case study:

Step 1: What is your problem?
- To identify and spatially locate different elements and key areas of green infrastructure based on the provision potential of ES?
- To aid a land use planning process by identifying the most important areas from the ES point of view?
- To get an overall picture of the ES supply of an area?
- To assess supply of, demand for and flows of ES?
- For detecting possible areas of conflict where multiple land use interests or needs for biodiversity conservation exist?

Step 2: Define the limits / borders of the study area
- The extent of the study area defines what should be taken into account in the analysis.
- If you work with, for example, a land use planning area, that defines what type of spatial datasets are needed.
- To avoid border effects, create a wide enough buffer around the study area and do the analysis using a union of the area and the buffer.

Step 3: Based on your problem
- Identify the set of ES you are targeting in the analysis.
- Decide on the ES classification you want to use. Modify it to fit your case by leaving out non-relevant classes or groups, and leaving out other ES classes or groups that you do not want to examine (but do not forget them).

Step 4: Identify the participants of the first focus group
- People who can help you identify the relevant scientific experts and key local stakeholders or actors to be invited to the scoring focus groups.
- People who can help you identify and locate the best available spatial datasets with regard to the set of ES in focus:
    - The level of detail of spatial datasets depends on the scale of the study area. -> The bigger the area examined, the coarser the scale.
    - Scale and resolution of spatial data matters when choosing datasets for evaluation:
        - National level analysis: a very general overview which should not be zoomed in;
        - Regional level analysis: local details cannot be taken into account;
        - Local level analysis: need for more detailed data;
        - Block / plot level analysis: data on small features, such as individual trees, bushes, green walls, etc., is needed.

Step 5: Arrange the first focus group
- Explain the context of your research and the key concepts carefully and objectively, including green infrastructure and ES with the help of a (simplified) ES classification. It can also be helpful to use the ES cascade to present the ES concept to land use planners, governance and management staff and other actors in an understandable way.
- Facilitate a discussion on:
    - Identification of relevant scientific experts (people attending the focus group can belong to them!).
    - Identification of local and regional experts if applicable.
    - The best existing spatial datasets (type, content, collected by whom, spatial extent, quality, update period, consistency, availability, administrator).

Step 6a: Compilation and preprocessing of data
- Collect the spatial datasets taking into account costs, individual researcher's 'property', privacy questions (e.g. socio-economic data) and dataset sensitivity (e.g. threatened species, valuable natural features in private land).
- Examine the extent and quality of the spatial data (does it cover the whole study area, is it available at reasonable cost for research purposes, is it up-to-date, is it of good quality, does the resolution of the data match the scale of the case study). Note any shortcomings of the data for later use and understanding. If the quality is good enough, proceed to preprocessing.
- Preprocess the datasets into comparable formats by extracting data subsets (e.g. groundwater areas of good quality) and combining different data layers into themes (see**Error! Reference source not found.**). Data may need to be converted from feature to raster format and the raster layers resampled to a common pixel size to ensure that the raster layers align with each other

spatially. Thematic layers are assigned a binary value of 0 or 1 indicating the presence or absence of the theme in a pixel.

- Preprocessing of quantitative datasets:
  - The data layers are converted into continuous raster layers, where the quantities of the original data are rescaled between 0 and 1.
  - As in the case of qualitative data, pixel value 0 represents the lowest, and pixel value 1 represents the highest provision potential within the study area.
  - Therefore, when quantitative datasets are available it is useful to denote pixels outside 'service providing units' as 0 and rescale the quantities of the service providing areas between e.g. 0.5 and 1 (the lowest value depends on how low the quantity is in regard to the highest value).

Step 6b: Scoring of the themes affecting ES provision potential

- The data themes are assessed in focus groups where participants assess the effect of each theme on the provision potential of each ES group and score the themes accordingly. The relevance of the themes to the provision potential of ES is summarized as median scores. Each theme has to be considered in relation to each ES group, because all themes are not equally relevant for all ES.
- This done by asking 'what effect does the theme in question have on the prerequisites of ES provision potential? For example, does the presence of a conservation area have a favourable or harmful effect on the ES 'Habitat and gene pool protection'? If the effect is favourable, the effect is scored as: very favourable (3); favourable (2); or slightly favourable (1). If the effect is neutral or the theme is irrelevant for the specific ES, a score of zero (0) is given. If the effect is harmful, the effect is scored as: slightly harmful (-1); harmful (-2); or very harmful (-3). Respondents are also allowed to respond as 'I don't know'. An example scoring is given in Table 1 below.

Table 1. Example of scoring of data themes on ecosystem service provision

DATA THEME	ES GROUP CODE																				
	P1	P2	P3	P4	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	C1	C2	C3	C4	C5
1. Conservation areas	0	2	2	2	0	1	2	3	2	2	3	2	2	2.5	2	2.5	3	3	2	3	3
2. Valuable landscapes	3	1.5	1	1	1	2	1	1	1	2	2	1	1	1	0	1	2	2	3	2	2
3. Valuable cultural heritage environments	2	1	0	1	0	1	1	1	0	2	1	1	1	1	0	1	3	1.5	3	2	2
4. Traditional agricultural biotopes	2	2	0	1	0	1	1	1	1	3	3	1	2	1	0	1	2	2	3	2	3
5. Important forest habitats	0	2	1.5	1.5	1	1	1	2	1	2	3	1	2	2	1	1	2	3	2	2	3
6. Undrained peatlands	0	2	2	2	1	0	1	3	1	1	3	1	2	2.5	1	2	2	3	2	3	3
7. Important bird areas	0	1	0	1	1	1	1	1	0	1	3	1	1	1	0	1	2	3	2	2	3
8. Valuable geological features	0	1	3	2	1	2	1.5	2	1	1	1	1	2	3	0	1	2	2	2	2	3
9. Groundwater areas	0	1	3	3	0	1	1	3	1	1	1	0	2	3	0	1	1	1	1	1	2
10. High Nature Value farmlands	3	1	0	0	0	1	1	1	0	2	2	1	1	1	0	1	2	2	2	2	2
11. Good and continuous agricultural areas	3	2	0	0	1	1	0	0	0	1	0	0	1	0	0	1	0	1	2	0	0
12. Surface waters of high or good ecological status	0	2	3	3	0	0	0	2	0	0	3	2	0	3	0	0	3	3	2	2	3
13. Surface waters with low or very low level of human-induced alterations	0	2	2	3	0	0	0	2	0	0	2	1	0	3	0	0	2	2	2	2	3
14. Regional recreation areas	1	2	1	1	0	2	1	1	1	1	1	1	1	1	0	1	3	2	2	2	2
15. Groundwater areas at risk	-2	-1	-3	-2	-3	0	0	-1	0	0	0	0	0	-3	0	0	0	0	0	0	-1
16. Sealed surfaces	-3	-3	-3	-3	-2	-1	-2	-3	-2	-2	-3	-1	-3	-2	-1	-2	-3	-3	-3	-3	-3
17. Land extraction sites	-2	-3	-2	-2	-2	-3	-2	-2	-1	-2	-2	-1	-3	-2	-1	-1	-3	-2	-2	-3	-3
18. Peat extraction sites	-2	-3	-2	-2	-2	-2	-2	-2	-1	-1	-2	-1	-3	-3	-2	-1	-3	-3	-3	-3	-3
19. Surface waters of moderate, poor or bad ecological status	-1	-1	-2	-2	-1	0	0	0	0	0	-1	-1	0	-2	0	0	-2	-1	-2	-2	-2
20. Sites of frequent algal bloom observations	-2	-2	-2	-2	-1	0	0	0	0	0	-1	-1	0	-2	0	0	-2	-1	-2	-2	-2
21. Surface waters with moderate or high level of human-induced alterations	0	-2	-2	-2	-1	0	0	-1	0	0	-1	-1	0	-2	0	0	-2	-2	-2	-2	-2

3: *Very favourable effect*, 2: *Favourable effect*, 1: *Slightly favourable effect*, 0: *No effect / neutral effect*, -1: *Slightly harmful effect*, -2: *Harmful effect*, -3: *Very harmful effect*.

Step 6c: Criteria for summarising the scores

- Unanimous answers: The median value of the answers is used in the summary if all respondents agree upon the direction of the causal relationship between the theme and the ES in question, for example, if all respondents give either a positive value [or zero] or all respondents give a negative value [or zero].

- Slight disagreements: Differing answers are excluded from the summary if less than 20% of the respondents disagree with the majority's opinion of the favourableness or harmfulness of the effect. Slight disagreements might result from misinterpreting the question and concepts involved.

- Clear disagreements: Value zero is used, if over 20% of the respondents disagree with the majority's opinion of the favourableness or harmfulness of the effect. This way the theme in question is interpreted not to have a clear effect on the provisioning potential of the specific ES in the analysis. Clear disagreements might result from a lack of unambiguous understanding of the causal effect between the theme and the ES or from significant complexities / uncertainties related to them.

Step 7: Analysing the spatial variation in ES provision potential using a GIS

- The pre-processed and rescaled quantitative data layers already represent the spatial variation in the provision potential of certain ES within the study area (e.g. groundwater supply, timber volumes of forests). Therefore, using the expert scores and overlaying qualitative data themes is not required to assess these ES.

- For other ES, the spatial variation in the provision potential is assessed using the pre-processed data themes and median scores (weights) obtained from the expert assessments in GIS software. First, each ES group is assessed individually by calculating a weighted sum of the preprocessed binary raster layers. The median scores for each data theme for the given ES are used as weights. Thus, a median score of 0 omits a data theme from the assessment of the ES group in question. The weighting can be implemented for example with the Weighted Sum tool in the Spatial Analyst extention of ArcGIS (version 10.1). The tool allows weights to be assigned to each layer and sums overlaying pixels into an output layer.

- The resulting layers for each ES are rescaled to a range of $0 - 1$. In the output, the pixel value 1 represents the area with the highest provision potential for the ES in question, and pixel value 0 represents the lowest provision potential within the study area. A value of 0 does not necessarily indicate that the location has no provision potential for the given ES, but it indicates that within the study region, other locations have greater potential for the provision of this particular service.

- The spatial patterns of each ES section (provisioning, regulating and maintenance, and cultural) can be analysed by summing the results of related ES groups according to the section they belong to, and normalising the results to a common range of $0 - 1$. All ES can be included as equally important in the synthesis, or weights can be assigned according to the importance of different layers.

- A full synthesis of the analysed ES can be created by summing up the layers for each ES section and rescaling the resulting values to a range of $0 - 1$. An example of such an ES synthesis map is shown in Figure 2.1.7).

Step 8: Visualisation of the results

- Once all desired ES groups are assessed individually and syntheses of different ES sections and all ES are made, the results are ready for visualisation. An intuitive way to present the results is to use a sequential monochromatic color scheme, where areas with highest potential are visualised with darker tones and areas with lower potential are visualized with lighter tones (**Error! Reference source not found.**). Depending on the distribution of the pixel values, different classifications of the pixel values can be used. Often, but not necessarily always, the pixel values are somewhat normally distributed. In this case, it is good to apply standard deviations stretch or quantile classification of the pixel values.

Step 9: Validation of the results

- After carrying out the analyses, it is recommended to validate the results with stakeholders and/or scientific experts who have expertise on the study area. Among possible methods for obtaining feedback on the results are individual fill-forms, focus group discussions, interviews, and interactive workshops.

- It is advisable to collect the feedback in such a way, that the comments can be attached to specific locations. This enables a more detailed analysis on the factors that affect the results in these locations. An easy way to collect this information is to use hard-copy paper maps and ask the respondents to pinpoint locations where they find the results either plausible or unconvincing / inconsistent etc. The targets can be marked with numbers, and justifications for each pinpointed target can be written down. These paper maps can then be scanned and georeferenced. In order to avoid digitizing paper copy maps, also online map surveys, or for example Google Earth can be used to get the feedback directly in GIS format.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	The need to collect new data depends on: (i) the objectives of the case study; (ii) the matrix-type method selected (based solely on LULC or based on a wide variety of spatial datasets as in GreenFrame method); and (iii) on the availability of data from the case study area.
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit datasets (vector or raster) and additional information are needed.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Basic knowledge in spreadsheets and GIS are needed to conduct the assessment successfully. Facilitating expert evaluations and focus groups needs social and stakeholder engagement skills as well as the ability to clarify the ES concept, ES categories, the content and quality of various spatial datasets, and the scoring task in an understandable and uniform way.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	Any general spreadsheet software (e.g. Excel, Lotus123, Google Spreadsheets) is suitable to collect data in tabular form. Before the data is imported into a GIS programme, the data must be saved to a database IV file (*.dbf) or Excel format (*.xls). The method can be applied using any type of GIS software, licensed (ArcGIS) or open source (GRASS, QGIS, R, etc). The LULC data should be in Shapefile format (*.shp) or a raster image (e.g. *.tiff, *.img), with LULC coding. The GIS software is needed to join the tabular data to the spatial data for the spatial analysis and creating output maps.
Time resources	☑ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources depend on the availability and accessibility of spatial datasets, on the need for pre-preparing the datasets for analysis, and on the expertise of the researchers and GIS specialists.

Economic resources	☑ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Similar to time resources.
Other requirements	When using GreenFrame, expertise is needed in carrying out focus groups and working together with researchers from other fields as well as with local and regional actors. Basic knowledge of statistics is also needed (understanding variation, mean, median, etc.).	

Where do I go for more information?

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Factsheet prepared by Leena Kopperoinen & Laura Mononen

ESTIMAP

Introduction

ESTIMAP is a consistent and flexible set of spatially-explicit models each of which can be run separately for the assessment of different ES at the European scale. They are all developed following the CICES classification (Haines-Young & Potschin, 2013) and framed in the ES cascade model which connects ecosystem structure and functioning to human well-being through the flow of ES. The models are dynamically linked to LUISA, the JRC land use modeling platform (Lavalle et al 2011). This provides the opportunity to evaluate the impact of different scenarios of land use changes on ES provision.

At present eight modules are operational at the European scale:

1. Capacity of ecosystems to remove air pollutants;
2. Capacity of land cover to prevent soil erosion;
3. Capacity of coastal ecosystems to protect against inundation and erosion from waves, storm or sea level rise;
4. Capacity for retention of water in the landscape;
5. Capacity of ecosystems to sustain pollination activity;
6. Habitat quality for breeding common birds;
7. Recreational and cultural services;
8. Bird richness of pest-control providers.

ESTIMAP was originally developed to support policies at a continental scale. Nevertheless the approaches are flexible and can be easily downscaled in order to fit the specific local scale needs and local planning demands of the OpenNESS case studies. This guide explains how to apply downscaled ESTIMAP-Recreation and ESTIMAP-Pollination models which have been extensively applied in OpenNESS case studies.

Keywords

Spatially explicit models, ecosystem services, mapping.

Why would I chose this approach?

ESTIMAP provides a framework for an exhaustive and consistent spatially-explicit assessment of ES. Each model is framed in three parts: (i) an indicator of the potential capacity of the ecosystems to provide the service; (ii) an indicator of the flow of the service; and (iii) an indicator of the demand of the service. It represents an integrated but data-intensive approach, based on the application of dynamic process-based models or data models which estimate ecological production functions which are subsequently used to map potential or actual ES.

What are the main advantages of the approach?

- The GIS models and processes are relatively easy to implement, requiring only a medium level of GIS expertise, especially for the data preparation;
- Mapping and visualisation facilitate dialogue among scientists, policy-makers and the general public;
- The models allow simulation of different scenarios and evaluation of different policy options;
- The models are flexible; they can be downscaled and modified in order to fit the local needs and conditions.

What are the constraints/limitations of the approach?

- Data preparation can be quite a long and demanding task;
- The utility of the results depend on identifying a clear set of questions to be addressed.

What types of value can the approach help me understand?

Estimap is designed as a quantitative tool and produces outputs that mostly provide biophysical values for regulating services. However the recreational indicator considers both supply and demand and reflects, to some extent, socio-cultural values associated with aesthetic beauty and recreation.

How does the approach address uncertainty?

The method does not address uncertainty explicitly.

How do I apply the approach?

Cultural ES are recognised as 'physical and intellectual or spiritual, symbolic and other interactions with biota, ecosystems, and land- /seascapes [environmental settings' (Haines-Young & Potschin 2013). Examples of cultural ES are: appreciation of natural scenery; opportunities for tourism and recreational activities; inspiration for culture, art and design; sense of place and belonging; spiritual and religious inspiration; education and science. Outdoor recreation and tourism represent an important service that interests millions of people and contributes to connecting them with nature. While tourism is an occasional activity, local outdoor recreation affects the daily life of people.

ESTIMAP-recreation provides models for mapping and assessing the potential provision of nature-based outdoor recreational opportunities (Paracchini et al. 2014) (Table 1).

Table 1. An overview of the ESTIMAP-recreation model.

General meaning of the indicator	Potential opportunities provided by ecosystems for a nature-based recreation activity
Method	Composite mapping
Components at the European scale	Degree of naturalness Natural protected areas Water-related data
Components at the local scale	The three components and their elements can be adapted to fit specific needs
Outputs	1. RP raster map (dimensionless) 2. ROS raster map (categories) 3. Demand (statistics)

It is framed in three parts:

- Recreation potential [RP] – capacity
  - The potential opportunities provided by the ecosystem for recreational activities (RP Map, D, in the figure below)
- Recreation Opportunity Spectrum [ROS] – flow
  - The flow of service, which combines the potential provision map (RP) with proximity map (P) (ROS Map, L, in the figure below). Proximity to roads and built areas is considered to be one of the main drivers of the service being used; people have to reach recreational sites and opportunities by transportation infrastructures. The Recreation Opportunity Spectrum (ROS), originally developed as a tool for inventorying, planning and managing recreation opportunities (Recreation Opportunity Spectrum Procedures and Standards Manual 3.0, 1998) is used to provide an indicator of recreation opportunities available.
- Estimate of potential trips – demand
  - The assessment of potential benefits: evaluates the percentage of potential trips for each ROS category (% PPB, N, in the figure below).

Figure 1 shows a flow chart of the steps within the model. Firstly, the model assesses the potential capacity of a group of identified ecosystems and other elements to provide opportunities for local outdoor recreation (D). This varies according to the presence of three key aspects: the degree of naturalness (A), the presence of natural areas (B) and the presence of water (C). In a second step, it computes Euclidean distances from urban (E) areas and from roads (F). The two maps are then combined to derive a proximity map (H), which depends on specific proximity parameters (G). A final map of recreation opportunities (ROS) (L) is then computed by a cross tabulation between the RP (D), the Proximity Map (H) using a second set of parameters (I) with thresholds for the degree of recreation opportunities provided by nature and the degree of proximity and remoteness. Parameters (G and I) can be derived from a literature review.
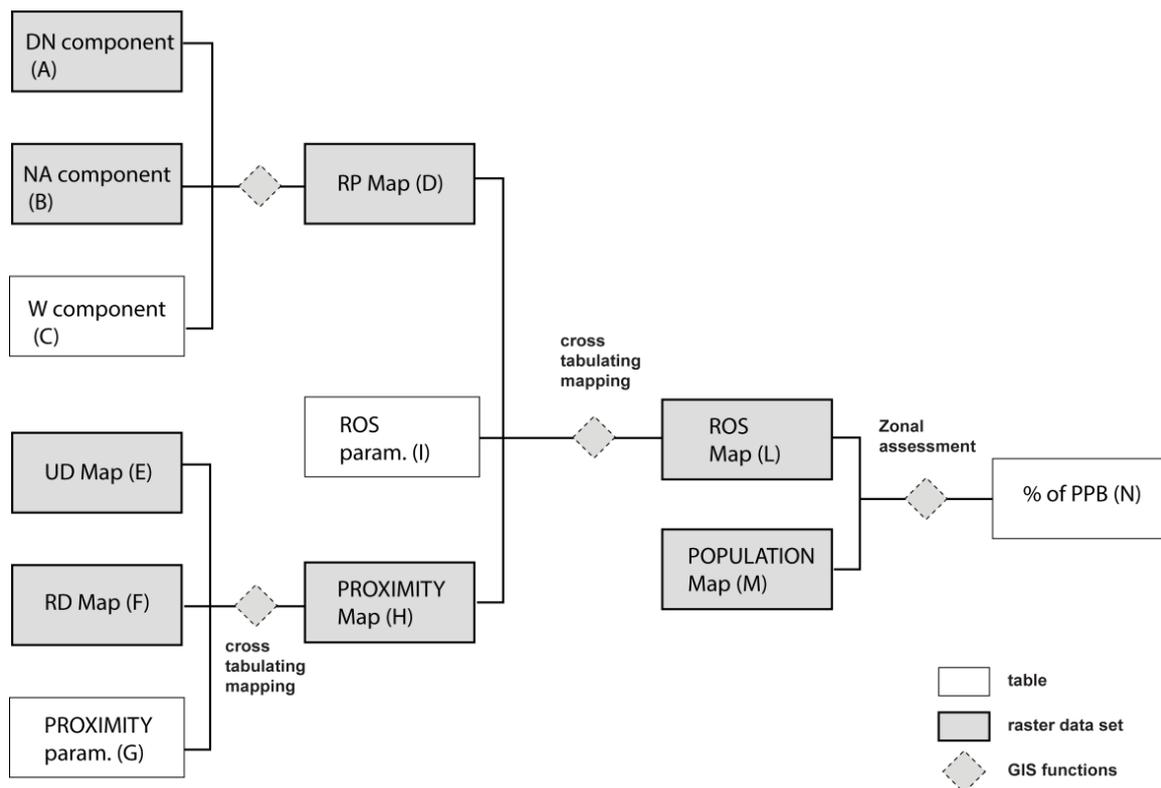
Fig. 1 Flow chart of the ESTIMAP-recreation model.

This model configuration represents the original model developed to fit the continental scale. To downscale the model to the local context, the first step is to determine the main questions to be addressed (see examples in table 2 below).

Table 2. Examples of different problems addressed in the OpenNESS case studies.

OpenNESS cluster	Example questions
Sustainable urban management	• What is the relative amount of recreational opportunities available per capita? • Is the local provision equally distributed? • Does the local management of urban parks and play grounds, and the local transportation network, fit citizens needs?
Management of mixed rural landscapes	• How are the opportunities for nature-based recreation spatially distributed inside the park? In terms of quality and accessibility? • Where are the most important conflict areas between nature conservation and recreation?
Integrated river basin management	• What is the value of the lake to local tourism and recreation? • Is this value affected by the water quality of the lake (link to the Water Framework Directive)?

Requirements

Data	☐ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	
Type of data	☑ Qualitative ☑ Quantitative	Spatially-explicit datasets (vector or raster) and additional information are needed.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	The models can be computed using any types of GIS software, licensed (ArcGIS) or open source (GRASS, QGIS, R, etc)
Time resources	☑ Short-term (< 1 year) ☑ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Time and economic resources strictly depend on the expertise of the researchers and GIS specialists
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	
Other requirements		

Where do I go for more information?

Paracchini, M. L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J. P., Termansen, M., … Bidoglio, G. (2014). Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. Ecological Indicators, 45, 371–385. http://doi.org/10.1016/j.ecolind.2014.04.018

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Factsheet Prepared by Grazia Zulian

Bayesian Belief Networks (BBNs)

Introduction

A Bayesian Belief Network (BBN) starts from a diagrammatic representation of the system that is being studied, developed by pulling together the knowledge of scientists and practitioners (both are stakeholders) about the processes leading to the supply and demand of ES. As a knowledge representation tool, this initial development of a BBN generates a framework of nodes and links, similar to many other representations of an ecological system or a human decision process (Figure 1). Its purpose is to formalise the flows of information through the system (from ecology to economics) and lead to transparency about what is being represented.
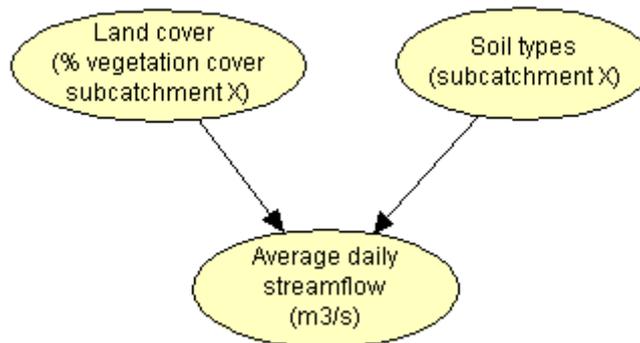
Figure 1: Simplistic representation of a BBN as nodes and linkages.

The next stage is populating the knowledge framework with information, which can include expert opinion, model outputs and empirical measurements (both quantitative and qualitative). If a statement based on that information, for example 'the colour of a leaf is green' compared to alternatives that the leaf could be yellow or brown, is an assertion, then the uncertainty can be seen as the weight of evidence that supports each assertion. Within a BBN there will be values that measure the weight of evidence for each possible assertion being true. Well-known probability theory is then used to provide inferences, i.e. conclusions based on evidence, in the form of the information and uncertainties within the outcome nodes.

The ES and natural capital (NC) concepts are by definition inter-disciplinary and logically fit into the framework of a decision process. The idea of value is only relevant when it is comparable to another value, rather than as an abstract concept, and the BBN can be extended to include decision-relevant information such as preferences and costs[11]. Therefore the BBN is an appropriate decision support tool that can be applied to many of the challenges of ES and NC assessment.

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[11] Technically this becomes an influence diagram (ID).

The BBN is very flexible and can also be used to model other methods, such as state and transition models (STM; see Section 2.4) and multi-criteria decision analysis (MCDA; see deliverable 4.3), and can be combined with other model frameworks, such as agent-based models, to improve realism in modelling socio-ecological systems.

Keywords

Object-oriented bayesian networks; Influence diagrams; Cost-effectiveness; Cost-benefit; Multi-criteria analysis; Decision-support.

Why would I chose this approach?

Types of problem

The BBN is a flexible tool that can be used in a number of ways. Particular features of the tool are relevant to its use in ES studies:

- *Compact model knowledge representation* - The BBN can be used directly for simple modelling tasks or represent the simulation output from a more complex model in the form of key input and output variables in a network with conditional probabilities. For example, the detail of a complex hydrological model may not be necessary when assessing the costs of flooding over a 10 year period. The simulated effect, e.g. of land cover and soil type, on run-off over a given area and time span can be summarised in the form of a conditional probability table within a BBN with two conditioning variables.
- *Linking knowledge domains* - The BBN can link diverse types of information, and be used as a meta-modelling tool to link together different models in a causal model chain. Through the use of object oriented BBNs (in a simple case these are hierarchies of nested BBNs) and dynamic BBNs (using time slices to model temporal dependences, feedbacks, etc.), the BBN can be extended and adapted to modelling very complex applications. This is relevant to ES studies, especially implementing the ES cascade or other types of driver-pressure-state-impact-response (DPSIR) model chains. This makes it a good methodological framework for a multi-disciplinary project, as it easily transitions from ecological delivery to social assessment to economic cost, if that is what is required.
- *Knowledge updating* - BBNs can be readily updated with new information, so it is not a static representation of the issues. Existing knowledge on the strength of causal relationships is updated according to how much the new evidence 'weighs' in relation to the old (e.g. how many new observations there are relative to the prior data).

Decision support

- *Constructing a shared causal model* - A BBN is readily adaptable to accommodate stakeholders' belief about the structure of causality and the amount of knowledge/uncertainty about each outcome. BBNs are easily used 'live' for exploring scenarios with stakeholders because model run time is instantaneous once compiled. Here, BBNs are used to construct a common understanding of the problem.
- *Expected utility of decisions* - No decisions are taken with true certainty. The BBN can be used as a decision support tool with a consistent treatment of uncertainty. Decision

alternatives can be associated with costs and multiple end-points can be associated with benefits. BBNs will compute the expected utility (net benefits) of decision alternatives. BBNs with multiple outcomes can also be set up as a multi-criteria analysis, using multi-attribute value functions with utility weights on each outcome (instead of monetary utility).

• *Value of information* - BBNs include diagnostics such as the value of information of each variable in the network in relation to a specified outcome. With information on the cost of additional observations, BBNs can help decision-makers determine whether the cost of information is justified by the net benefits of making a better decision.

• See also Factsheet on 'Object-Oriented Bayesian Networks for Decision Support'.

Scale relevance

The BBN is developed at the temporal and spatial scales chosen by the knowledge engineer (person responsible for constructing the BBN), and these must be defined clearly at an early stage in each study. Explicit choices on temporal and spatial scale follow automatically once the ES under study have been properly defined with geographical boundaries and time frames. There is also a scale of complexity so the BBN delivers sufficient detail without overloading the model with irrelevant information; this has to be appropriate to the individual study and can be tested through formal analysis and stakeholder interactions. The BBN is specific to the scales chosen, so any change of scale will often lead to a change in BBN structure or quantification.

The inputs and outputs are also linked to the scales of the BBN, and there is a significant challenge to upscale and downscale data from a variety of sources to make the information appropriate at the correct scales for the BBN.

Spatially-explicit

The BBN operates on the domain that is specified by the knowledge engineer using the scales of space and time, and these should identify the unit that is appropriate to make the decision. For a regional government looking at the decision of whether or not to increase the area of forestry, the BBN would model one regional decision process, which will often rely on summaries of supplementary spatially-referenced data such as maps to inform the process. The decision is not to plant a specific tree at a particular location; it is to provide a policy of increasing forestry by a certain amount across the region. The decision process itself is not spatial, and neither is the BBN.

A BBN can be embedded within a GIS where it does become spatially-explicit, but it also inherits the constraints of a GIS system in terms of representing spatial dependence. Here, the BBN models the functional relationships between the states of nature represented by the GIS layers, and these are generally based on a raster or polygon with uniform information across the geographical unit. There is a possibility of capturing local spatial dependence by using information from neighbouring geographical units, but it is more difficult to include correlations or dependences that occur across longer distances.

What are the main advantages of the approach?

- Easy to use once some experience has been gained;
- Quick to use;
- Recognised and established approach;
- Advanced state-of-the-art method;
- Draws on existing data, can handle missing data, and expert knowledge can be included;
- Useful in a participatory approach with stakeholders;
- Naturally an integrative/holistic approach;
- Spatially-explicit where required;
- Covers a wide range of ES;
- Trade-offs can be evaluated in terms of expected utilities of alternative decisions;
- Temporal capability through dynamic BBNs;
- Naturally set up for use in scenario analysis;
- Uncertainty can be managed;
- Can be constructed incrementally;
- Easily updated with new data as it becomes available;
- Easy to deploy a model on a website to enable stakeholder interactions with the model, also useful during model construction.

What are the constraints/limitations of the approach?

- The detail within a BBN is restricted by the use of classes or states to record information;
- Continuous variables must be discretised when BBNs are used with utility nodes for decision support; this discretisation may lead to some information loss / loss of resolution;
- Uncertainty is defined by the chosen spatial and temporal scale, the complexity of the causal structure of the network and the resolution/discretisation in the model; experience is required in finding the right balance between these sources of uncertainty, given the purpose of the BBN.

What types of value can the approach help me understand?

BBNs are incredibly flexible and can be used to provide information on most kinds of value.

How does the approach address uncertainty?

All inputs and outputs in a BBN have an associated uncertainty which is propagated throughout the network using Bayesian conditional probabilities.

How do I apply the approach?

There are three generic steps in setting up a BBN: (i) identify the structure (nodes and links); (ii) parameterise the structure (using conditional probability tables (CPTs), equations, and/or learning from data cases); and (iii) run options and scenarios including tests on the structure, sensitivity analyses, etc. These three steps are interspersed with a number of stakeholder consultations, as

illustrated by the flow diagram shown in Figure 2.3.2. One advantage of using a BBN is that it can be set up to allow stakeholder consultations to interact with the program, so options suggested at these meetings can be explored in real time and stakeholders can engage fully with the development of the structure. The BBN could be embedded within a GIS but the process of construction and testing remains the same.
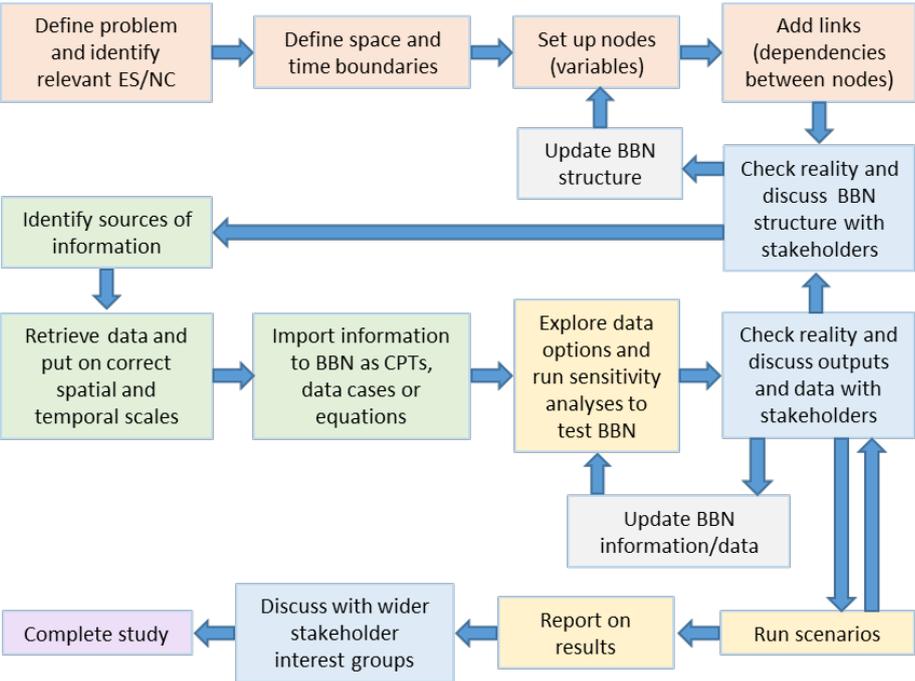
Figure 2: Flow diagram showing the steps required to develop and apply a BBN.

Requirements

Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	Data are always available through the use of expert knowledge, so there is never a need to wait for new data before exploring possibilities. BBNs are excellent at integrating knowledge by providing a framework to combine expert opinion and data within a single model.
Type of data	☑ Qualitative ☑ Quantitative	Handles all types of input information, but internally the software holds it as qualitative data.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields	Very useful in an inter-disciplinary study and where working with stakeholders (of all backgrounds) is important.

	☑ Work with non-academic stakeholders	
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	Software is available either free or on licence.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Short-term to get models working, explore potential frameworks, and get the most out of available data.
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	<6 person-months, longer time will be required if there is a lot of stakeholder interaction and/or there is no initially agreed model structure.
Other requirements		

Where do I go for more information?

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Factsheet prepared by Ron Smith, Anders L. Madsen & David N. Barton

State and Transition Models

Introduction

State-and-transition models (STMs) are conceptual models of ecosystem dynamics after disturbances based on alternate state theory (Kachergis et al. 2011). In contrast to succession theory, which predicts that ecosystems recover from disturbances and return to a reference (undisturbed) state, alternate state theory maintains that disturbances may trigger a regime shift in critical processes (e.g. population recruitment, nutrient cycling) (Westoby et al. 1989) that will maintain the ecosystem in a state that differs from the reference state. The new state has different structural properties (e.g. functional diversity, species composition and dominance) from the reference state. The disturbances that trigger these changes are natural factors (e.g. droughts, windfalls, fire), management (e.g. clear-cutting, grazing by domestic animals), and the interactions among them; and the shifts in ecosystem condition that they trigger are irreversible in the absence of specific interventions. STMs acknowledge non-linear responses of ecosystem properties to human interventions; alternate states represent abrupt changes in ecological properties.

Given the magnitude of human disturbances on ecosystems (http://www.anthropocene.info/en/anthropocene) and how these are linked to ecosystem condition, a model of ecosystem responses to these factors can be very useful to guide the management of ecosystems and of the goods and services that they provide. STMs are used in this context: they have been increasingly adopted to represent ecosystem changes that result from management in interaction with natural biotic and abiotic drivers (see recommended reading). In OpenNESS, we use the framework as a tool to operationalise, gain a common understanding of, and communicate the importance of ecological functions and processes that underpin the provision of ES in a particular ecosystem.

STMs combine the representation of alternate states and the factors that drive the transitions among states with tables of qualitative descriptions of the states. The benefits of STMs are that they are diagrammatic, low cost, flexible and suit participatory modelling (Nicholson & Flores 2011). Participatory modelling can bring together diverse knowledge holders, build shared understanding about complex systems and create useful models to understand the system of interest (Knapp et al. 2011). When implemented as Bayesian Belief Networks, they can be a powerful tool to communicate uncertainty about state categorisation and of the factors that trigger transitions between states.

Keywords

Why would I chose this approach?

STMs provide the opportunity to represent ecosystems and the provision of ES as process-based and dynamic models, making explicit the critical ecological functions underpinning the provision of ES, and the drivers that affect them. Hence, they complement frequently used models of ES provision that are based on spreadsheet/GIS approaches of spatial indicators (i.e. scoring of land cover/land use typologies and landscape elements: see OPENNESS factsheets on Simple and Advanced Matrix approaches), by offering a mechanistic model of ecosystem condition as a function of ecosystem management. However, STMs can be spatially-explicit (Bestelmeyer et al. 2009) and can be used for land and territorial planning, through mapping of ecosystem states.

Scale of the model
The ecosystems that are modelled with STMs occur under specific physical conditions (i.e. a forest under certain soil and climate characteristics). Alternate states are the result of management (i.e. grazing, wood extraction, tree species planted), of natural factors (droughts, floods, wind) and of their interactions. Hence, STMs are suitable to model ES at the local scale (e.g. farm level) and at regional scales, covering areas with the same soil and climatic conditions. For example, one of the STM applications in OpenNESS modelled the Nothofagus antarctica (Ñire) forest occurring in northern Patagonia.

STMs are also applicable to other systems that present threshold responses. In particular, the diagrammatic visualisation in STMs helps to further the understanding of land managers and supports their participation in the development of the model (Nicholson & Flores 2011).

Decision objectives
STMs are models of ecosystem dynamics, and therefore appropriate to model the consequences of management decisions and other actions on ecosystem condition and on the level of ES provision. By modelling the biophysical components of the cascade model, STMs are suitable for operationalising the 'cascade model cycle', making explicit the consequences of decisions about ES delivery on the capacity to sustain multiple ES provision. STMs can be used in the context of adaptive management (Rumpff et al. 2011), to maintain the provision of ES within sustainable ranges (avoiding degradation thresholds), and to evaluate the consequences of actions (management and policy) on multiple ES, including the analysis of trade-offs among ES and cost-benefit analysis. In OpenNESS we explicitly use STMs to address decision-making questions related to forest and freshwater system dynamics and the impacts of these decisions on levels of ES provision.

What are the main advantages of the approach?

- Easy to use: The graphical approach, the independence from any pre-defined functional relationships and the possibility of including different sources of knowledge makes STMs a very flexible and easy to use approach;
- STMs are increasingly being applied as an approach to guide the management of ecosystems and their ES, including to assess the risk of degradation of ecosystem condition; to take proactive measures to avoid degradation; to identify specific intervention strategies and

promote desirable transitions based on ecological knowledge; and to set restoration targets (Bestelmeyer et al. 2010);

- In the context of ES assessments and modelling, STMs provide a new way of describing the underlying functions that support ES provision. It is a process-based approach to the management of ES, in which management interventions are drivers of ecosystem condition and ES provision levels;
- STMs draw on existing data from various sources and are suitable for both participatory knowledge integration and communication;
- States can be mapped, if suitable spatial data are available;
- STMs can be used in scenario analysis and are especially useful to inform adaptive management (Rumpff et al. 2011);
- STMs have an integrative approach of ecosystem functioning in response to management;
- STMs are very suited for implementation as a BBN. In these cases, ecosystem processes and management factors are modelled in a decision-support context, taking into consideration uncertainty (Bashari et al. 2009, Nicholson & Flores 2011).

What are the constraints/limitations of the approach?

- They are specific to an ecological site, so extrapolation to other conditions is limited, but knowledge on similar or comparable sites may be used to complete missing information (Bestelmeyer et al. 2010);
- The identification of thresholds and alternative states is sometimes management driven, with limited correspondence with ecological processes and real ecological thresholds. The thresholds may then be misleading. However, the models must not be understood as static, but rather as representing the best ecological knowledge about a system at a particular time, which should be tested and updated as more knowledge is generated;
- Ecological thresholds can be triggered by interacting drivers at various spatial scales (Peters et al. 2004). These may be difficult to capture without appropriate data and analysis, and/or with other knowledge based on long-term experience (Knapp et al. 2011). Also in this case, STMs must be seen as a representation of the existing knowledge about the system that needs to be open to updates as new knowledge is available;
- The degree of uncertainty about states and thresholds is often not made explicit, although this is very much recommended. Recent implementation of STMs with BBNs provides a promising alternative to overcome this problem;
- STMs may be more demanding than other forms of ES mapping, but the level of demand depends on the ecological knowledge and long-term experience about the case study;
- If implemented as a BBN, the level of model complexity needs to be evaluated prior to building the model (Nicholson & Flores 2011). There are different options to overcome a potential model complexity challenge.

What types of value can the approach help me understand?

STMs are designed for biophysical values. However they may be implemented within a broader approach to consider the socio-cultural or economic implications of a transition within the study area.

How does the approach address uncertainty?

STMs can be implemented as BBNs to explicitly model uncertainty. This refers specifically to the probability of the system being in a particular state as a function of the initial condition and the different levels of the factors (natural and management) that drive change (Rumpff et al. 2011). BBNs provide a powerful combination of predictive, diagnostic and explanatory reasoning (Nicholson & Flores 2011). STMs can be the basis for an ES cascade model if implemented as a BBN. BBN-STMs have been modelled in different ways. For instance, based on participatory modelling, Bashari et al. (2009) characterised the states of a rangeland in Queensland, Australia, derived from grazing pressure, fire and climate.

Nicholson & Flores (2011) provide two different BBN models to represent the STM in Bashari et al. (2009). First, they show the implementation in a variant of Bayesian networks – so-called dynamic Bayesian networks (DBNs) – that allow explicit modelling of changes over time. In a second model, they propose a combination of STMs and DBNs. They compare the different BBN implementations of STMs, with a focus on model complexity analysis. They show that the complexity of each model depends on the inherent structure in the problem being modelled, and conclude that for the models to be tractable, the number of transitions from each state needs to be limited, and only influenced by a small number of causal factors. They recommend an assessment of model complexity prior to any detailed modelling.

How do I apply the approach?

Building of a STM requires the identification of a reference state for a particular ecological site or ecosystem, and of the alternative states that result as a response to human interventions in interaction with the physical environment (climate, soil, nutrient contents, etc.). The reference and alternate states need to be described in terms of a series of state variables that characterise the state's ecological structures and functions (e.g. tree cover, species diversity, species composition, primary productivity, nutrient cycling). Then the drivers, natural factors and management interventions that affect state variables and that trigger change (i.e. transitions between states) have to be identified. A next step is to link the drivers of change with the states (as in Bashari et al. 2009) or with state variables (as in Rumpff et al. 2011) and to produce a catalogue of transitions. The model is revised and refined through literature searches and consultations. If the STM is implemented as a BBN, the conditional probability tables in the model have to be elicited.

In OpenNESS, we aimed to link state variables, a representation of ecosystem condition, with levels of ES provision. In this situation, two further steps are required once the STM is built: (i) to identify the important ES provided by the system, and (ii) to link levels of ES provision to levels in the state variables. In this way, the biophysical structures and functions that support ES provision are made explicit. The steps are summarised below and in figure 1:

- Step 1: Identify reference and alternate system states. This is based on specific structural characteristics, that can be recognised in the field or from data and that derive from use.

Information can be derived from historical maps, field experience, scientific data, and/or local knowledge.

- Step 2: Prepare a catalogue of state variables. This step consists of identifying the structural and functional variables that characterise the states. The list is built from literature reviews, data from monitoring programs, and general knowledge about the system.
- Step 3: Build a graphical model of the states and transitions among them, including the levels of the variables associated with the transition. More than one model can be built if there are different beliefs about state transitions and underlying drivers of change.
- Step 4: Prepare a catalogue of factors that determine transitions, and describe them. In Rumpff et al. (2011), for instance, the factors are classified as 'independent environmental variables', 'processes' and (short time scope) 'management actions'. Identify time periods in which responses are expected to manifest.
- Step 5: Incorporate transition factors. Link transition factors to changes in states or state variables.
- Step 6: Refine the model iteratively.
- Step 7: Identify important ES provided by the system. Prepare a catalogue of ES and ES benefits.
- Step 8: Incorporate ES and benefits. Link levels of ES provision and benefits to states or state variables.
- Step 9: If implemented as a BBN, establish conditional probability tables.
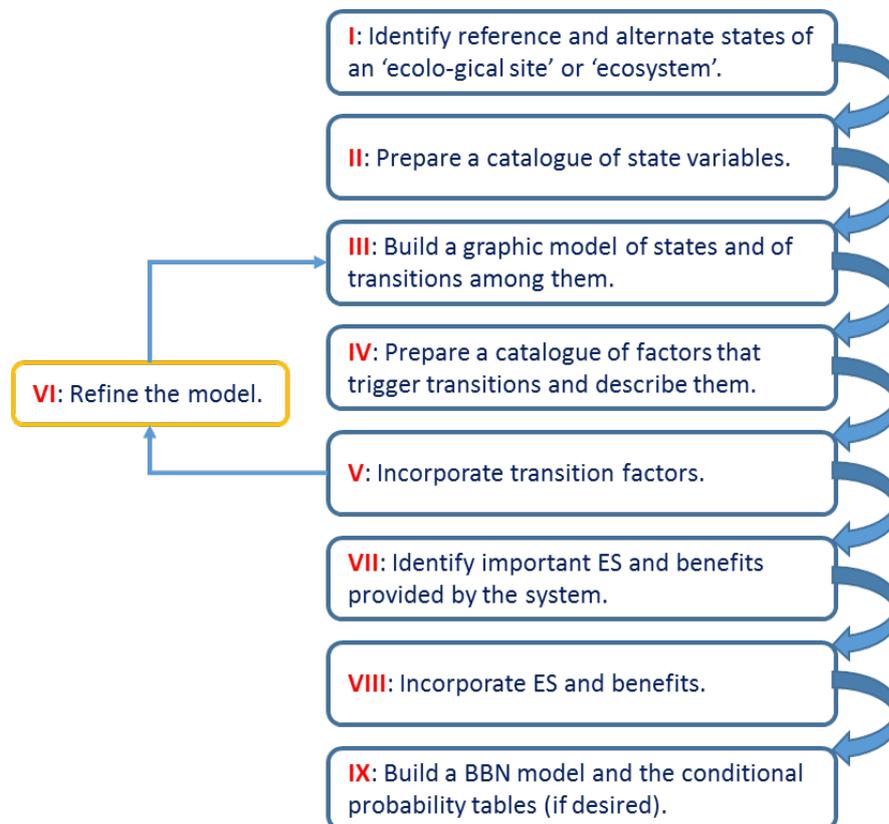
Figure 1. Steps required to build a STM, linked to ES and implemented as a BBN. Based on Rumpff et al. (2011).

Requirements

Data	☑ Data is available ☐ Need to collect some new data ☐ Need to collect lots of new data	STMs are built using different kinds of knowledge sources, i.e. historical maps and remote sensing data, time series/monitoring data, field measurements and ground-truthing, experiments, expert and practitioner's knowledge (Bestelmeyer et al. 2010).
Type of data	☑ Qualitative ☑ Quantitative	Both
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields ☑ Work with non-academic stakeholders	STMs are used to capture all kinds and sources of knowledge that can help understand ecosystem dynamics.
Software	☑ Freely available ☑ Software licence required ☐ Advanced software knowledge required	There is no need for any software to build an STM. But, if implemented as a Bayesian Belief Network (BBN), the model will require the corresponding licence.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	STMs are generally built with the intention of putting together all existing knowledge about a system one is familiar with. In this sense, time resources required can be < 1 year, but this assumes that most of the data and information are assembled in advance. Modelling of ES in STMs (linked to state variables) requires additional data such as primary productivity, tree growth, meat production, recreational value, and information about other cultural services.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	Between 6-12 months depending on the level of information available and the kind of analysis to be performed.
Other requirements	If implemented as a BBN (as has been the case in the OpenNESS studies), it requires knowledge about BBN modelling, software, and licences.	

Where do I go for more information?

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Factsheet prepared by Graciela M. Rusch, Dardo López, Verónica Rusch, Pablo Peri, Andrea Goijman, Laurence Carvalho & Anders L. Madsen

METHOD FACTSHEET

Species Distribution Models

Introduction

Species distribution models (SDMs) (Franklin, 2009) have shown great potential in helping to achieve conservation planning goals by refining our knowledge of species distributions (Jetz et al., 2012). SDMs extrapolate species distribution data in space and time, usually based on a statistical model. These models identify areas that are ecologically suitable for the presence of species (Soberon & Peterson, 2005; Hirzel et al., 2002; Franklin, 2009). Use of SDMs can help to support management decisions with regard to biodiversity (Pawar et al., 2007; Baldwin, 2009; Franklin, 2009). Many examples can be cited that have made extensive use of SDMs for different applications, for example, assessing global impacts, prioritising or targeting areas for protected status, assessing threats to those areas, predicting species distributions in unsurveyed areas and designing reserves (Araùjo & Williams, 2000; Pearce & Ferrier, 2000; Thuiller, 2003; Araújo et al., 2004; Elith et al., 2006; Romero-Cacerrada & Luque, 2006; Elith et al., 2010). SDMs can be applied to vegetation or animal distribution modelling; several examples exist in Europe of their application to species, species groups, guilds, alliances or communities (for vegetation).

There are a wide variety of SDM methods, each with their own characteristics. The BIOMOD methods are discussed here specifically because they are used in the OpenNESS case study 5 (forest planning in the Vercors Mountain Range, France), (Thuiller, 2003; Thuiller et al., 2009; http://cran.r-project.org/web/packages/biomod2/index.html). BIOMOD is a platform for ensemble forecasting of species distributions, enabling the explicit treatment of model uncertainties and the examination of species-environment relationships (Thuiller et al., 2009). It includes the ability to model species distributions with several techniques (see a summary in Figure 1), test models with a wide range of approaches, project species distributions into the future using different climate scenarios and dispersal functions, assess species temporal turnover, plot species response curves, and test the strength of species interactions with predictor variables. Computationally, BIOMOD is a collection of functions running within the R (CRAN) software (programmed in the R language) and allows the user to apply a range of statistical models to several dependent variables using a set of independent variables. Thus, BIOMOD attempts to span the different approaches that can be used in habitat suitability modelling. It does not aim to be exhaustive, but it presents the most commonly used modelling approaches and the ones considered to be the most interesting and robust and which are implemented in R (see http://cran.r project.org/bin/windows/base/).

	Model	Concept	Technique	Environmental variables types	Key references
SRE	Rectilinear Envelope	Environmental envelope	Equivalent to Bioclim. Climatic Envelope Model is a GARP-simulation	Cont	Busby 1991, Nix 1986 ; Walker & Cocks, 1991; McMahon et al. 1996
CTA	Classification Tree Analysis	Decision tree	Classification and regression	Cont/Cat	Breiman et al., 1984
RF	Random Forest		Classification and regression	Cont/Cat	Breiman, 2001
GBM	Generalized Boosting Model	Regression and decision tree	Combination of regression decision Trees & "boosting"(method combining several simple models to improve predictions performance)	Cont/Cat	Jerome H. Friedman, 1999
FDA	Flexible Discriminant Analysis	Regression analysis	Classification method by using Friedman's (1991) multivariate adaptative regression spline, using the MARS function for the regression part of the model.	Cont/Cat	Hastie, T., Tibshirani, R and Buja, A.,1994 Manel, D., Dias, J. M., Buckton, S. T. and Ormerod, S. J.,1999
MARS	Multivariate Adaptive Regression Splines		Linear model	Cont/Cat (only Cont in Biomod2)	Friedman, 1991
GAM	Generalised Additive Models		Additives model	Cont/Cat	Guisan et al., 2002, Pearce & Ferrier, 2000
GLM	Generalised Linear Models		Linear models / additives models/least square fitting	Cont/Cat	Guisan et al., 2002, Pearce & Ferrier, 2000
ANN	Artificial Neural Networks	Machine learning	Neural nets	Cont/Cat	Pearson et al., 2002
Maxent	Maximum entropy		Maximum entropy	Cont/Cat	Phillips et al., 2006

Figure 1. Summary of the models that can be used within BIOMOD (Le Roux, 2013). 'Cont/Cat' = Continuous/Categoric.
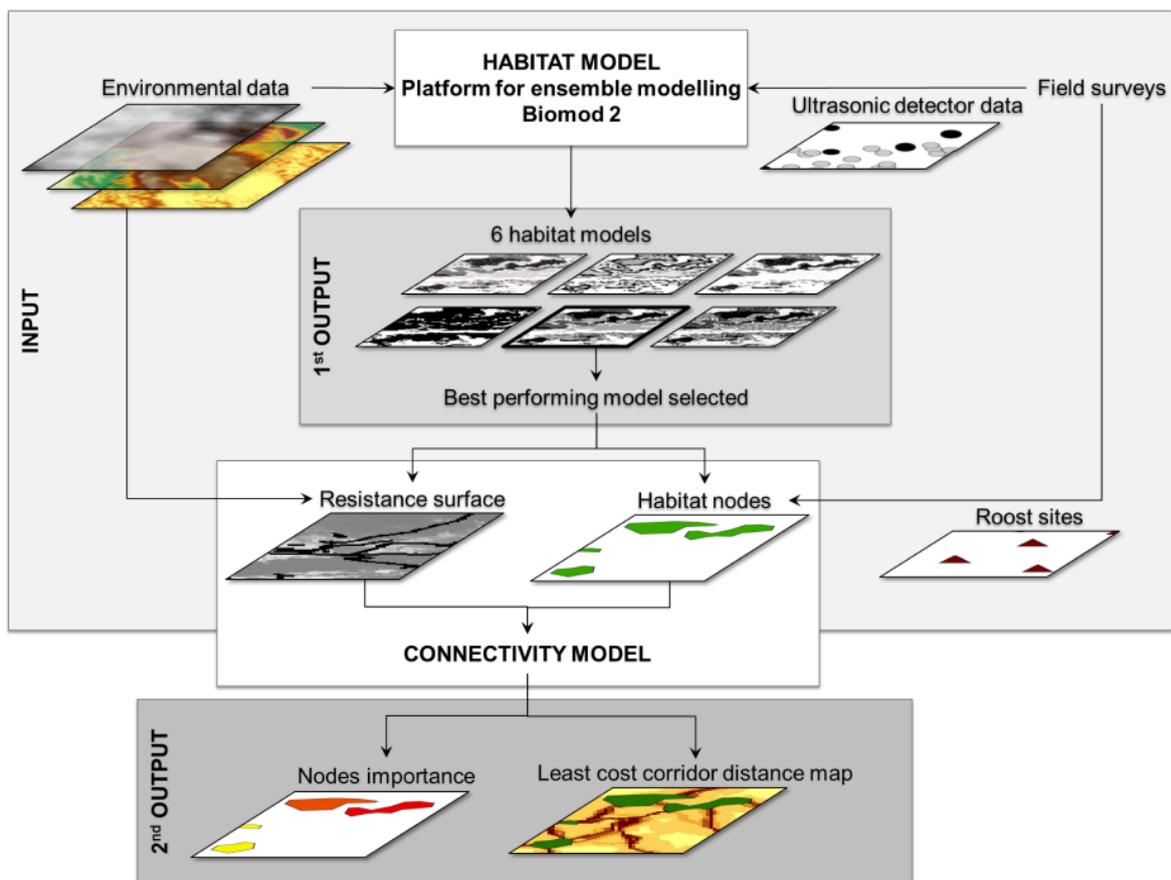

Figure 2. Conservation planning with spatially explicit models: a case for horseshoe bats in complex mountain landscapes. Source: Le Roux et al. (2017)

Keywords

Species distributions; Climate change; Suitable climate space; Biodiversity; Spatial approach.

Why would I chose this approach?

If it was important to understand where the climate might be appropriate for species in the future. Information on climatic suitability for the species that make up a habitat may provide a valuable first step towards understanding the ecosystem services that habitat may provide under different future climatic conditions.

What are the main advantages of the approach?

- Can identify areas where climate and/or habitat is appropriate for a given species;
- Can be used to explore multiple future scenarios;
- Spatial outputs produced with accompanying goodness-of-fit statistics;
- Freely available.

What are the constraints/limitations of the approach?

- Some species are very hard to model as the factors driving their present-day distributions are unclear;
- As with any modelling, some species fit better with the driving variables and produce projections that are more statistically significant than others;
- Relatively advanced statistical process underly the models; mathematical and technical expertise are required to interpret the results;
- The projections reflect the climate, environmental characterisitics and/or habitat niche that a species could potentially use – it does not usually take into consideration other factors such as predation, competition or disease, or changes over time in factors such as habitat distribution.

What types of value can the approach help me understand?

SDMs can provide information to support biophysical valuation. They also provide information about impacts on future habitats and species and so information that can support assessment of other values that depend on these species: for example suitability for key crop/timber species or those with particular regulatory (e.g. key carbon-sequestering or soil regulating species) or cultural significance (e.g. spiritually significant or emblematic species). With a temporal perspective they can be used to illustrate the potential impacts on intrinsic, existence and bequest values.

How does the approach address uncertainty?

The approaches will usually provide some metric of match to baseline conditional (a goodness-of-fit for the model). Sensitivity testing can be applied to explore the impacts of uncertainty around the input variables on the robustness of the results.

How do I apply the approach?

The majority of SDMs (e.g. most of the modelling approaches within BIOMOD) require data on the presence and absence of species, but it is possible to work only with presence data[12]. The presence/absence species data may be related to a wide variety of environmental variables, including habitat parameters, temperature, soil moisture, NDVI[13], slope, aspect, distance to wetlands or rivers, and evapotranspiration index. The environmental variables that should be included depend on the knowledge of the species or groups of species to be modelled. The information which is entered into the model should relate in some way to the distribution of the species being modelled (e.g. they should limit or control the distribution of the species in some manner). Some of the models used, such as Maxent, were specifically designed for presence-only data, and to overcome problems of small samples.

Instructions to implement BIOMOD2 are freely available in Thuiller (2012), Thuiller et al. (2012) and Georges & Thuiller (2013). The steps in the BIOMOD2 modelling process are:

1. Gather all available and meaningful GIS information (as outlined above). All GIS layers have to share the same projection system (e.g. WGS 84). GIS layer resolution depends on the original data, but may be degraded to speed calculation if fine-resolution layers are not crucial for the species studied. The spatial extent needs to be specified (the calculation time will depend on its surface area). All layers need to be supplied as rasters (using conversion tools if necessary in GIS software). Raw GIS layers may need to be adapted, e.g. by first producing a map of distance to a river from an original river map and then converting this to a distance-to-river map as a raster.

2. Data on observed species distributions can be provided either as .csv data with three columns providing geographical coordinates and presence/absence data, or as a raster from GIS software. Note that more than three columns can be provided if you are modelling more than one species.

3. Install BIOMOD2, R-Cran, the latest version of Java and Maxent (following the instructions provided in Georges & Thuiller, 2012); the following links will be needed:
   - http://cran.r-project.org/web/packages/biomod2/index.html
   - http://www.cs.princeton.edu/~schapire/maxent/
   - http://cran.r-project.org/bin/windows/base/
   - http://www.oracle.com/technetwork/java/javase/downloads/index.html).

   Different R packages need to be installed: biomod2, abind, sp, raster, rastervis, lattice, latticeExtra, RColorBrewer, hexbin, grid, nnet, gbm, survival, splines, gbm, mda, class, randomForest, rpart, pROC, plyr, rgdal, zoo (for further information see http://cran.r-project.org/web/packages/available_packages_by_name.html). The tutorials listed in the links above explain how to carry out the analyses.

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[12] Presence/absence data maps in detail where a species is present and also where it is absent; presence data only maps roughly where it is known to be present.

[13] Normalised difference vegetation index – an indicator of photosynthetic activity and hence vegetation productivity.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Depending on the availability of data within the case study and the species in question. The resolution of the case study will also determine the extent to which suitable data are available both in terms of species and contextual datasets. Collecting primary species data is a considerable task: in most cases SDMs depend on secondary data collation rather than collection of primary data.
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☐ Work with researchers from other fields ☐ Work with non-academic stakeholders	In general, SDMs require expertise from the ecology/biodiversity field, but input from non-academic stakeholders can be useful to validate the results.
Software	☑ Freely available ☐ Software licence required ☑ Advanced software knowledge required	Depends on the species distribution model in question. Some are freely available for download, others are embedded in particular institutions. BIOMOD is implemented in R statistical coding landuage and is a freeware, open source, package. SPECIES is implemented as standalone interface.
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Depending on the level of available data can be performed in less than a year. Will depend on the level of skill of the programmer and the level of pre-processing required to create the driving variables.
Economic resources	☐ < 6 person-months ☑ 6-12 person-months ☐ > 12 person-months	
Other requirements		

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Factsheet prepared by Sandra Luque, Marie Le Roux, Frederci Archaux, Paula Harrison & Robert Dunford

METHOD FACTSHEET

RUSLE (Revised Universal Soil Loss Equation)

Introduction

The Revised Universal Soil Loss Equation (RUSLE) is an empirical erosion model recognised as a standard method to calculate the average risk of erosion on arable land. It developed from the Universal Soil Loss Equation (USLE) developed in the US Department of Agriculture and has other similar variants such as the Modified USLE (MUSLE) and ABAG (Allgemeine Bodenabtragsgleichung = 'General Soil Loss' in German). As all these models use similar algorithms and produce comparable results, we focus on RUSLE here.

The method is efficient in terms of costs for data provision, model parameterisation and modelling. The results of the RUSLE model can also be coupled with the SITE land use model.

Keywords

Soil loss; Erosion model; Standard method.

Why would I chose this approach?

The method is universally recognized as a standard method for soil loss monitoring. It is relevant for ecosystem services related to soil erosion and protection.

What are the main advantages of the approach?

- RUSLE provides international applicability and comparability of the results and methods, as the method has been adapted to and applied in many world regions.
- The results are plausible in terms of assessing risks of water erosion.
- The algorithms can be implemented based on literature values or adapted to empirical / statistical data by using standard GIS software.
- Required input data are usually available and easy to obtain.

What are the constraints/limitations of the approach?

- RUSLE is used to estimate the *average* long-term risk of erosion on arable land. It is not designed for modeling soil erosion and sediment transport under individual rainfall events.
- Due to the relatively simple empirical approach, the typical erosion processes such as splash erosion, soil transport and soil deposition are not considered as a dynamic process.
- Antecedent soil moisture and soil stratification are not considered.

What types of value can the approach help me understand?

RUSLE is used to identify soil loss, as such it can be used to supply biophysical values related to soil erosion/preservation.

How does the approach address uncertainty?

The model does not explicitly address uncertainty.

How do I apply the approach?

The following input data are required as GIS datasets:
- Average annual precipitation (raster dataset);
- Digital soil map with information regarding the top soil layer;
- Digital Elevation Model (DEM);
- Digital land use data about land use classes and objects that inhibit erosion (barriers);
- Data on crops.

Once provided with this set of data, the RUSLE model links erosion factors influencing soil erodibility (K factor), erosivity (R factor), land cover and management (C factor), slope length (L factor) and slope (S factor). By multiplying these factors, the mean relative soil loss in tons per hectare per year is calculated. The calculation can be based on GIS grid cells or polygons such as crop fields. The factors contributing to erosion risk are location-specific and climate-specific. Due to the countless applications of RUSLE, various nomograms, equations and modelling approaches are available supporting users to determine the individual RUSLE factors (see e.g. the USDA reference below, which provides excellent online support).

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☑ Need to collect lots of new data	This will strongly depend on the case study; all three may or may not apply.
Type of data	☐ Qualitative ☑ Quantitative	
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☐ Work with non-academic stakeholders	
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	

Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

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Factsheet prepared by Jörg Priess, Christian Schweitzer & Christian Hoyer

SOCIO-CULTURAL METHODS

Deliberative valuation

Introduction

Deliberative valuation is not one particular valuation method, but it is a valuation paradigm (Raymond et al. 2014) providing a framework to combine various tools and techniques that bridge citizens and academia, as well as different disciplines within science. Deliberative valuation is based on the assumption that valuation is a social process in which values are discovered, constructed and reflected in a dialogue with others (Wilson and Howarth 2002). Therefore, deliberative valuation invites stakeholders and citizens (the general public) to form their preferences for ecosystem services together through an open dialogue, which allows consideration of ethical beliefs, moral commitments and social norms beyond individual and collective utility (Aldred 1997, Satterfield 2001, Wegner and Pascual 2011).

Keywords

Deliberation; Public engagement; Participation; Discourse; Relational values; Social values; Equity.

Why would I chose this approach?

Deliberative valuation is considered particularly appropriate when valuing ecosystem services and benefits derived from them, because they are common goods, the existence of which have consequences for other people, in other parts of the world, and across generations. These choices are fundamentally ethical and hence the right question is not what "I want for me" (reflecting the self-oriented values that follow individual rationality) but rather what is "right to do" (reflecting the others-oriented values that follow collective rationality) (Vatn 2009, Chan et al. 2012). Open discourse, generated by deliberative techniques, is able to unfold relational values and reflect upon the social context of valuation. Therefore, deliberative methods are also proposed to account for social equity issues in valuation (Wilson and Howarth 2002). Deliberative valuation is particularly suited for understanding the meanings that people attribute to ecosystems and their services, such as holistic concepts of the land, and it can accommodate diverse world views and forms of information. Therefore, deliberative valuation is found helpful for addressing cultural ecosystem services such as traditional knowledge, sense of place, spiritual value and cultural diversity (e.g. Chan et al. 2012, Kenter et al. 2011), and can also be used to promote social learning (Kenter et al. 2015) by engaging the general public in an open discussion about the intrinsic (ecological) value of ecosystem functions and processes (e.g. Kelemen et al. 2013) or the value of nature for future generations (i.e. bequest values).

As previous field experiences prove, deliberative valuation can be applied in several decision contexts including; 1) awareness raising through learning at the individual or the group level (e.g. Aldred and Jacobs 2011, Kenter et al. 2011), 2) priority setting (e.g. Randir and Shriver 2009), 3) instrument design (see e.g. Maynard et al. 2015 where deliberative valuation of ecosystem

services served as a basic input for renewing regional development plans and nature protection rules), 4) mediation between conflicting interests (rather than liability) (e.g. Málovics and Kelemen 2009) and 5) opening up institutional mechanisms to bottom-up decision making processes and public engagement. In more rigid, top-down institutional systems deliberative valuation might seem to be less relevant for decision makers. Since deliberative valuation employs a huge number of tools and techniques from various disciplinary backgrounds, both the spatial scale and the spatial resolution of the valuation process range from the very small to the very high.

What are the main advantages of the approach?

- Contributes to balancing the power asymmetries between stakeholders:
    - by giving voice to more marginalized social groups and
    - by empowering them (if necessary) ;
- Integrates various knowledge forms (e.g. local, traditional, expert, scientific);
- Allows for social learning among the participants and the general public ;
- Improves the understanding of plural and incommensurable values and hence contributes to framing and managing conflicts;
- Increases the legitimacy of decisions that build on the outcomes of deliberation.

What are the constraints/limitations of the approach?

- Operates with small samples which are not statistically representative (although political representativeness can be achieved);
- Timely process requiring professional skills;
- It has to be combined with other approaches (e.g. MCDA) to reach quantitative results;
- Its success partly depends on participants' availability and general debating culture;
- Participation fatigue might emerge;
- Some institutional contexts are less open towards public participation.

What types of value can the approach help me understand?

Deliberative valuation is highly appropriate to elicit sociocultural values and those value dimensions which are directly related to the quality of life (human well-being). They can also be used to elicit economic values if they are combined with monetary approaches (e.g. deliberative monetary valuation), although the interpretation of results might be challenging from a philosophical point of view.

How does the approach address uncertainty?

Uncertainty can be addressed in the public dialogue, mainly qualitatively.

How do I apply the approach?

Since deliberative valuation is not one method per se, it is difficult to provide a stepwise description of how it goes in practice. In Table 1 we propose a toolbox approach along three major steps within a general deliberative valuation process.

Table 1. Steps within a Deliberative Valuation process

Steps of the valuation process	Main objective	Proposed tools
Problem framing	Understand the main problems related to ecosystem management through the eyes of local stakeholders and commit them to the valuation process	Stakeholder analysis and in-depth interviews (these are general techniques with no deliberative characteristics)
Knowledge co-generation	Co-generate knowledge with local stakeholders and citizens on the local perceptions of ecosystem services, and initiate an open dialogue to form preferences to ecosystem services collectively	citizens' science applications, photovoice method, focus groups variations (concept mapping groups, photo elicitation groups)
Decision support	Broaden and democratize the decision making process by involving the general public and / or the local stakeholders	citizens' juries, MCDA

Requirements

Data	☐ Data is available ☐ **Need to collect some new data (e.g. participatory valuation)** ☐ Need to collect lots of new data (e.g. valuation based on surveys)	The amount of new data to be collected depends on existing knowledge and information about the situation. In most cases the joint problem framing and the knowledge co-generating phase involves data collection.
Type of data	☐ **Quantitative** ☐ **Qualitative**	Both qualitative and quantitative data can be used in DV processes.
Expertise and production of knowledge	☐ Working with researchers within your own field ☐ **Working with researchers from other fields** ☐ **Working with non-academic stakeholders**	In most cases DV processes engage researchers from different disciplines. Public participation is an inherent part of DV.
Software	☐ **Freely available** ☐ License required ☐ Advanced software knowledge required	Many DV tools and techniques are low-tech by nature, but if DV is used in combination with other approaches (e.g. choice experiment, MCDA), licences may be required.
Time resources	☐ Short-term (less than 1 year) ☐ **Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	The length of DV processes varies between a few months and several years, depending on the issue at hand and the commitment of the decision maker and stakeholders.
Economic resources	☐ Low-demanding (less than 6 PMs) ☐ **Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	The organization and facilitation of the DV events as well as the analysis and communication of results require a rather strong involvement on behalf of the scientists.
Other requirements	Professional facilitation and communication skills.	

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Factsheet prepared by Eszter Kelemen and Heli Saarikoski

Participatory GIS

Introduction

Participatory mapping of ecosystem services consists in assessing the spatial distribution of ecosystem services according to the perceptions and knowledge of stakeholders. It encompasses different approaches including Participatory GIS (PGIS) and Public Participation GIS (PPGIS) (see Brown and Fagerholm, 2014) to which we broadly refer here as PGIS. In PGIS a plurality of stakeholders can participate in the creation of a map of ecosystem services, including local stakeholders and community members, environmental professionals and technicians, members of environmental NGOs, decision-makers, scientists, etc. PGIS can therefore integrate the perceptions, knowledge (local-based or technical) and values of different stakeholders and presents the outputs in the form of a map of ecosystem services (Fagerholm et al., 2012; Raymond et al., 2009). Most common used methods in PGIS for data collection include web-based surveys, face to face interviews and workshops. The results obtained allow similar data treatment as for non-participatory mapping methods (analysis of trade-offs, correlation analysis among services or with other aspects such as land use change, etc.) (Palomo et al., 2014; Sherrouse et al., 2011). PGIS is being increasingly used in recent years due to its potential for: including stakeholder´s perceptions in ecosystem services spatial assessments, incorporating different types of knowledge, mapping ecosystem services in data scarce regions, enhancing capacity building and social learning, and integrating stakeholders in a democratic process-oriented approach to decision-making (Fagerholm and Palomo, forthcoming).

Keywords

Stakeholders; Geographical Information Systems (GIS); Map; Values; Social learning.

Why would I chose this approach?

PGIS both enables the integration of different knowledge types, perceptions and values into ecosystem services spatial assessments, as well as providing a more democratic approach to decision-oriented science than using GIS approaches alone. Some types of ecosystem services, such as cultural services, might naturally be better mapped using PGIS than non-participatory methods, due to their direct link to people's perceptions and values (Plieninger et al., 2013). PGIS has been used to map all service categories as well as the spatial distribution of ecosystem services supply and demand (Palomo et al., 2013; Burkhard et al., 2012). It has also been applied to compare the perceptions of stakeholder groups towards the spatial distribution of ecosystem services (García-Nieto et al., 2014). PGIS usually achieves better outcomes when mapping ecosystem services at the local scale (than GIS approaches alone), and can be applied in different decision-making contexts, from awareness raising to priority setting and instrument design. The main methods for PGIS (web-based surveys, face to face interviews and workshops), and associated approaches such as the matrix approach, allow flexibility in the stakeholder selection and prioritisation processes, as well as

in the general requirements for applying the method (Burkhard et al., 2012; Fagerholm and Palomo, forthcoming).

What are the main advantages of the approach?

- Integrates stakeholder perceptions, knowledge and values regarding ecosystem services (methodological and operational advantage).
- Allows the involvement of multiple stakeholder types and thus creates awareness and fosters social learning related to ecosystem services (methodological and operational advantage).
- Some ecosystem services (such as cultural services) fit well with this mapping approach (methodological and operational advantage).
- Permits mapping ecosystem services in areas where spatial data is unavailable (methodological and operational advantage).
- The GIS skills needed to develop this method are relatively simple (methodological advantage).

What are the constraints/limitations of the approach?

- The development of best practices or guidelines for the method is still on going.
- PGIS methods have been mostly applied at local scales and integration of results into decision-making at larger scales has been elusive.
- The comparability among studies is usually low.
- The spatial resolution of the results and accuracy might be lower for certain services than for other approaches.

What types of value can the approach help me understand?

Participatory GIS is especially suitable for capturing ecological and socio-cultural values as well as instrumental and relational values related to quality of life. The method is not suitable for capturing monetary values.

How does the approach address uncertainty?

The approach does not explicitly address uncertainty

How do I apply the approach?

A PGIS study usually begins by identifying the most suitable method for data collection (surveys, interviews, workshop) and the relevant stakeholders to participate (e.g. a broad sample, certain key stakeholders, etc.) to achieve the overall aims of the study. Afterwards the methodology is developed in detail, sometimes deciding which ecosystem services will be mapped and sometimes letting stakeholders map the ecosystem services they choose from a list. A map, usually a topographic map, is designed or acquired for the mapping process. After the process of mapping, data is digitalised or analysed according to the research objectives. Results are usually presented to participants as part of the dissemination process.

Requirements

Data gathering	☑ **Low-effort** ☑ **Medium-effort** ☑ **Intensive-effort**	Depending on the number of participants and the method used the requirements will vary considerably.
Type of data		
Expertise and production of knowledge	☐ Unidisciplinary ☑ **Interdisciplinary** ☑ **Transdicisplinary (includes local knowledge)**	While some methods such as surveys and interviews allow interdisciplinary production of knowledge, other such as workshops (deliberative mapping) allow transdisciplinarity.
Software	☐ Only researchers ☑ **Researchers and non-academic stakeholders**	Allows inclusion of multiple stakeholder types.
Time resources	☑ **Short-term (months for getting accurate output)** ☑ **Medium-term (1-3 years)** ☐ Long-term (more than 3 years)	Time resources vary accordingly to the data collection method, and also to the planned spatial analysis of the data that are undertaken.
Economic resources	☑ **Low-demanding** ☑ **Medium-demanding** ☐ High-demanding	This will vary depending on the number of participants and the spatial analysis to perform after data collection.
Other requirements		

Where do I go for more information?

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Factsheet prepared by Ignacio Palomo

Photoseries analysis (for ES supply)

Introduction

Revealed preference for Cultural Ecosystem Services (CES) and spatially-explicit data on location for nearby CES provision can be obtained from popular social networks. Photoseries databases can be acquired from photo-sharing websites such as Flickr, Panoramio and Instagram. The analysis of community-contributed photos can be used as a complementary technique to interviews, questionnaires or focus groups to assess preferences for CES, assuming that visitors are attracted by the location where they take photographs. The method allows those CES to be identified which are perceived as the most important by the people who take the photographs and to map their distribution.

Keywords

Cultural ecosystem services; Non-monetary values; Photo-analysis; Social media platforms; Social perceptions.

Why would I chose this approach?

This method represents a pragmatic way of gathering space-and time-referenced data on observed people preference related to cultural ecosystem services which are difficult to obtain in a cost-effective way through traditional data gathering techniques (e.g. social surveys). The method allows an understanding of the spatial distribution of cultural ecosystem services in areas with low baseline information (Martínez-Pastur et al. in press).

The objectives addressed by photoseries analysis are the identification of socio-biophysical features of landscapes associated with cultural ecosystem services provision and the spatial trade-offs and synergies among cultural ecosystem services (Martínez-Pastur et al. in press).

The analysis of geo-tagged photographs from social networks can be used to assess the actual provision of different cultural ecosystem service categories, including recreation, aesthetic, intellectual and existence.

The method can be used for awareness raising, it allows the identification of focus areas where landscape plans and ecosystem management strategies should take into account the actual provision of non-material benefit of ecosystem services.

The method can be applied at different spatial scales, ranging from municipality to nation, according to context. It has been already applied at the continental, regional and city scale (e.g. Martínez-Pastur et al. in press, Richards and Friess, 2015, Tenerelli and Luque, 2015, Willemen et al., 2015). The method is based on volunteered geographic information whose resolution depends on several factors (mainly the accuracy of the used GPS-enabled devices, or the map scale used to specify the photo location). Count data can be produced at different cell sizes, from 1da to 10 km2, depending

on the chosen platform and geographic region (Zielstra and Hochmair, 2013), density of photographs, and scale of analysis.

What are the main advantages of the approach?

- Photoseries analysis represents a pragmatic way of gathering space-and time-referenced data on observed people's preferences related to CES which are difficult to obtain in a cost-effective way through traditional data gathering techniques (e.g. social surveys);
- It allows further understanding on the spatial distribution of CES in areas with low baseline information (Martínez-Pastur et al., in press);
- It permits the identification of socio-biophysical features of landscapes that are associated with the provision of CES and with the spatial trade-offs and synergies among CES (Martínez-Pastur et al., in press).
- Ease of use
- Speed of use
- Draws on existing data
- Allows for spatially explicit analysis
- Allows the identification of focus areas where people benefit from cultural ecosystem service provision

What are the constraints/limitations of the approach?

- Socio- and psycho-cultural aspects are crucial in order to define different values from the point of view of individuals and society. This method doesn't allow information related to the user characteristics to be directly obtained which could reveal significant correlations with the photo content;
- People's attitude to taking photographs change with the different recreation activities (Wood et al., 2013). Certain activities are therefore less well represented, for example rock climbers may take less photos than people having a picnic;
- The photo-sharing community may not be representative of specific social groups: the represented population will then be dependent on the level of access to information technology, education and age, and the user's ability/willingness to correctly geotag the photos;
- To appraise the importance of CES services through the number of uploaded photographs entails an inherent bias related to the interpretation of the photos by researchers and to the capacity to photograph certain CES. For example, it is quite challenging for researchers to identify sacred areas or traditions in photographs (Martínez-Pastur et al., in press).

What types of value can the approach help me understand?

Photoseries is predominantly used as a means to understand socio-cultural revealed preferences for cultural ecosystem services such as recreation, species appreciation, aesthetic beauty and cultural/natural heritage.

How does the approach address uncertainty?

The approach does not explicitly address uncertainty, but efforts to address this important issue are underway on a follow up work.
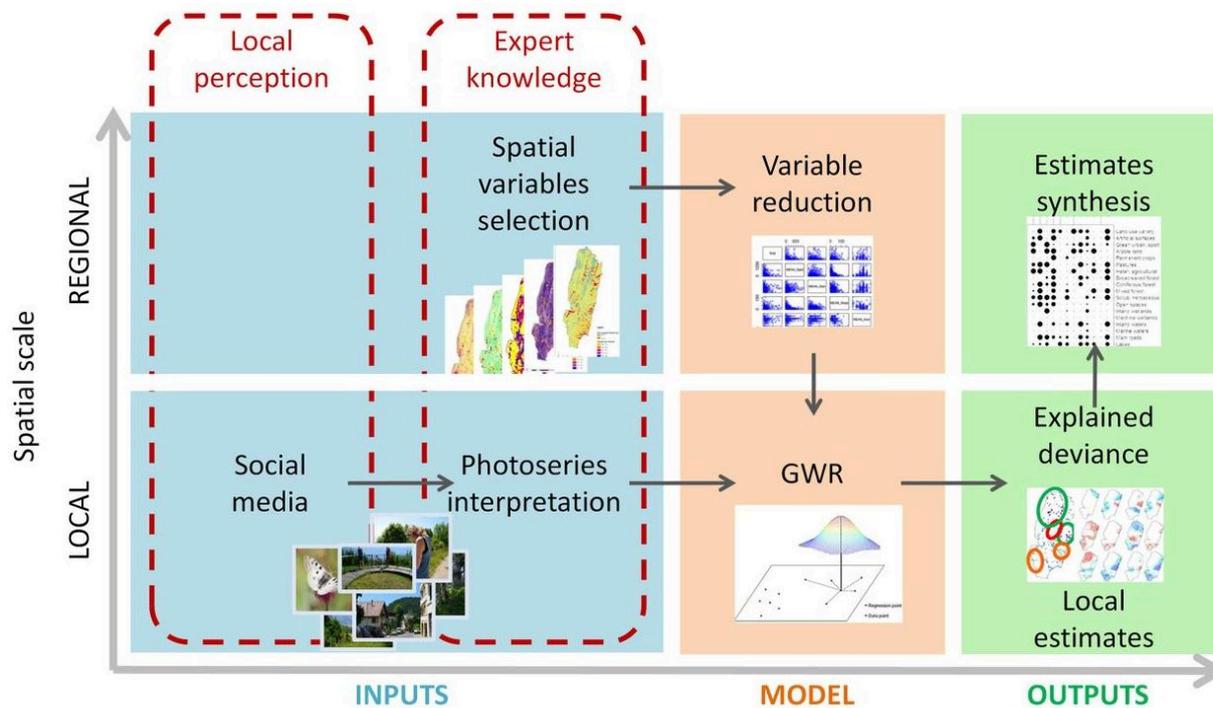

Figure 1. Framework used to analyze the photos withint the framework of OpenNESS

How do I apply the approach?

The photoseries analysis consists of a classified set of pictures downloaded from a selected social network. The number of photographs uploaded on the most popular social media for photo sharing (Flickr, Panoramio or others) should be compared in order to identify the platform with the highest number of photos. There is not a given definition for the necessary numbers of photos; for case studies with a large area extension a sampling strategy may be used. Guidance on sampling can be obtained from Richards & Friess (2015) who simulated different levels of sampling effort using a boot-strap resampling method. Rights in relation to the use of the photos will depend on the country and the use. Only photos entered as public should be used and the photo and the users' personal data must not be published. GIS information on environmental characteristics and infrastructures which may affect the CES should also be captured.

An Application Programming Interface (API) can be used to retrieve all the geotagged public pictures uploaded on the image hosting website for a given area (e.g. Flickr API). Some APIs allow the query to be limited to photographs with the most precise recorded accuracy level (street level); other sampling strategies may be used to reduce the number of pictures.

A hierarchical classification scheme is used to classify the different CES, and the different sub-categories are selected according to the specific study area characteristics. The photo classification is conducted through a systematic visual analytic process. This process can also be performed in a GIS environment which allows the different information layers to be overlaid, such as satellite images and thematic maps. All photos which are not related to CES and those which are tagged with the wrong location should be deleted through the systematic visual analysis, based on expert knowledge and multi-media supporting data (background satellite images, virtual globes and land use/land cover data). In general, it is possible to classify around 50 photos in 1 hour. Different professionals should discuss the photo content in order to agree on the interpretation.

Once the classified photoseries has been created the data can be analysed on a GIS platform in order to identify spatial trends. Different multivariate statistical analysis and spatial regression models can be applied to identify environmental properties which represent the major predictors of nearby recreation and other associated CES.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Public photos can be downloaded from social networks.
Type of data	☐ Qualitative ☑ Quantitative	Number of uploaded photographs. Socio-biophysical features associated with CES supply.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Different professionals should discuss the photo content in order to agree on the interpretation. Other methods such as interviews, questionnaires or focus groups should be integrated in order to take into account socio and psycho-cultural aspects which are related to values.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☑ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	☑ < 6 person-months ☐ 6-12 person-months ☐ > 12 person-months	
Other requirements		

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Factsheet prepared by Patrizia Tenerelli, Sandra Luque & Berta Martín-López

Narrative assessment of ecosystem services

Introduction

Narrative methods aim to understand and describe the importance of nature and its benefits to people with their own words. By using narrative methods we allow the research participants (residents of a certain place, users of a certain resource, or stakeholders of an issue) to articulate the plural and heterogeneous values of ecosystem services through their own stories and direct actions (both verbally and visually). Narrative methods usually collect qualitative data from individuals, but they can be also suitable to measure some aspects of human-nature relations in quantitative or semi-quantitative terms. They can be combined with more structured methods (both non-monetary and monetary ones) such as preference assessment, time use study, choice experiment or multi-criteria decision analysis (MCDA). In this guide we use the term 'narrative methods' as an umbrella term under which several tools from ethnographic, historical and qualitative social scientific research are brought together (e.g. in-depth and semi structured interview, observation, voice and video recording of events, artistic expression).

Keywords

Interview; Observation; Ethnography; Ethnoecology; Oral history; Qualitative analysis.

Why would I chose this approach?

Narrative methods do not constrain research participants to valuing nature within one dominant frame (i.e. the frame of ecosystem services which understands nature as the provider of goods and services) but allows them to articulate their values freely, in accordance with their own worldviews (de Oliviera & Berkes 2014, Satterfield 2001). Therefore, narrative methods can improve understanding around why certain ecosystem services are important to people, can shed light on the bundled qualities of cultural and social values linked to ecosystem services, and can highlight hidden aspects of human-nature relationships (Klain et al. 2014, Gould et al. 2015).

These methods can be applied to any ecosystem services, but the key area where they are most frequently used is the assessment of cultural ecosystem services (CES). Narrative methods are also proposed to identify bundles of ecosystem services (both in the supply side and in the demand side, in terms of socio-cultural values).

Narrative methods are frequently applied to collect background information on actual land use patterns and the motivations and perceptions driving land use decisions of individuals, households or communities (de Oliviera & Berkes 2014). They can also be useful in highlighting gaps between scientific and local knowledge (Rodríguez et al. 2005, Kaplowitz and Hoehn 2001). Information collected through narrative methods can be feed into awareness raising campaigns but can also be used to inform priority setting processes or instrument designs as part of deliberative processes, suggested by some complex valuation studies (e.g. Pereira et al. 2005, Palomo et al. 2011). Narrative methods are suitable to apply at lower spatial scales (from property to municipality or to a region including several municipalities). The spatial boundaries should be well-defined and meaningful to the participants. Spatial resolution differs from method to method. If narrative valuation is

combined with mapping, fine resolution can be achieved. Using mainly verbal and visual expressions often implies coarse resolution of spatial data. In sum, narrative methods can perfectly complement local level hybrid and integrated assessments using multiple methods by collecting background information, understanding local perceptions and engaging stakeholders in the valuation process.

What are the main advantages of the approach?

- Makes it possible to include local and traditional knowledge in the process of valuation;
- The valuation process and its results are inclusive and accessible for a large variety of different stakeholders;
- Allows participants to articulate the values of ecosystem services in their own terms and worldviews;
- Allows the elicitation of plural and heterogeneous values ;
- Highlights the bundled qualities of ecosystem services.

What are the constraints/limitations of the approach?

- The process is often lengthy and may require significant inputs from scientists;
- The topic of the research or some of the prompts can be difficult to conceptualize by local resource users, avoiding scientific jargon is therefore crucial;
- Since the researcher is personally involved in the study, her/his presence can influence the outcomes;
- Uncertainty about the quality of answers exists, therefore triangulation of data sources and methods might be necessary;
- Produces lengthy textual outputs (descriptions, narratives) which are difficult to quantify and to generalize at larger spatial or social scales;
- Strong responsibility on the scientists' side to not 'overuse' the participants.

What types of value can the approach help me understand?

Narrative methods are highly appropriate to elicit sociocultural values, but not suitable for monetary values (especially use values). Narrative methods, however, are capable of providing contextualized and qualitative information on how different value dimensions (including ecological and economic) are interpreted and framed by individuals or local communities.

How does the approach address uncertainty?

Uncertainty can only be addressed in narrative ways (i.e. by asking the study participants about their opinion/experience about future uncertainties).

How do I apply the approach?

Narrative valuation involves various methods, such as observations, semi-structured or in-depth interviews, storytelling or drawing exercises, which all have their own logical sequence and which are well described in existing literature on qualitative social scientific methods. Hence we provide here a rather general, stepwise approach to illustrate how narrative methods can be applied to assess the values related to ecosystem services (Figure 1).

Figure 1. Key steps for narrative valuation.
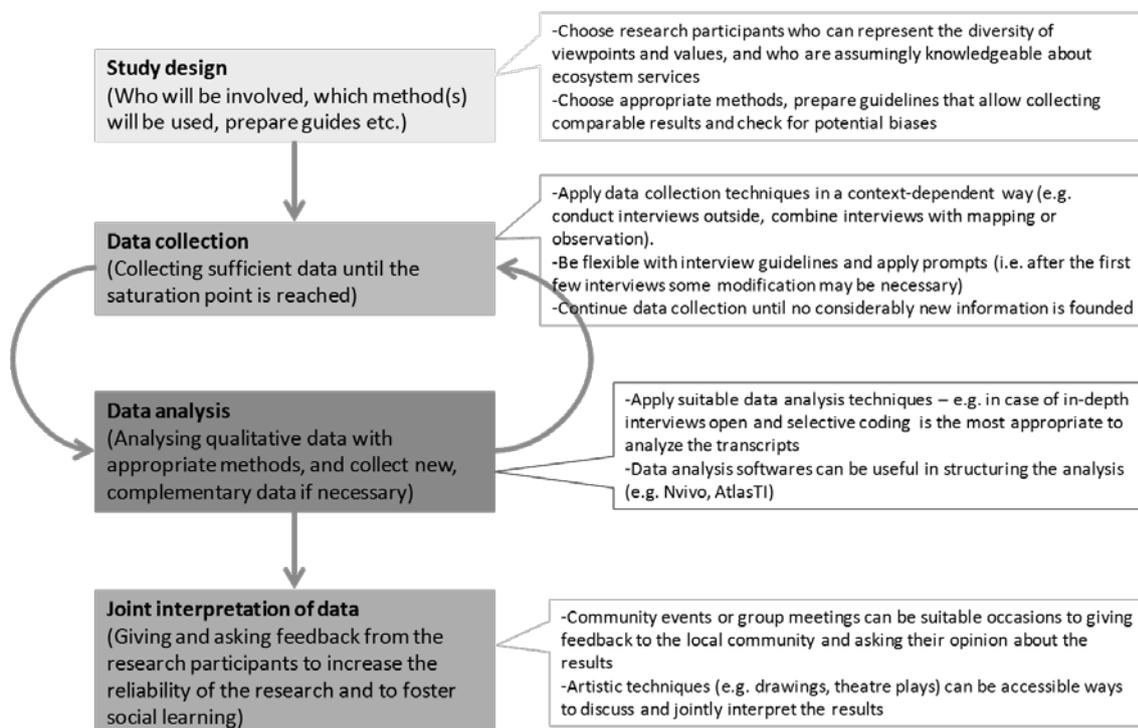
Data collection and data analysis are usually iterative steps of the process, new data is collected if the analysis highlights knowledge gaps or controversies, until the saturation point is reached (i.e. newly collected data does not add significant new knowledge to the process). According to some empirical results, the saturation point for understanding the diverse conceptualization of values linked to ecosystem services is around 30 in-depth interviews within a local community (including one or a few settlements) (Gould et al. 2015).

Requirements

Requirements		Comments
Data	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) ☐ **Need to collect lots of new data (e.g. valuation based on surveys)**	Collecting new data through interviews, observations etc. is key for narrative methods.
Type of data	☐ **Quantitative** ☐ **Qualitative**	Predominantly qualitative, but some quantifiable data can be collected.
Expertise and production of knowledge	☐ Working with researchers within your own field ☐ Working with researchers from other fields ☐ **Working with non-academic stakeholders**	Information is collected from non-academic research participants. They can also be involved in interpreting the data.
Software	☐ **Freely available** ☐ License required	Many narrative methods are low-tech by nature, but data analysis may require

		licensed software (e.g. Nvivo for qualitative analysis)
	☐ Advanced software knowledge required	
Time resources	☐ Short-term (less than 1 year) ☐ **Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	Required time ranges from medium to long-term, also depending on the nature of the study (e.g. ethnographic studies are often longer than 2 years)
Economic resources	☐ Low-demanding (less than 6 PMs) ☐ **Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	Medium to high-demanding, depending the exact nature of the method.
Other requirements	Social scientific and good communication skills are required, often the personal presence and participation of the researcher in local events is necessary to collect and interpret data.	

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Factsheet prepared by Eszter Kelemen

Preference assessment surveys

Introduction

Preference assessment is a direct and quantitative consultative method for analyzing perceptions, knowledge and associated values of ecosystem service demand or use (or even social motivations for maintaining the service) without using economic metrics. It can also be used to understand which ecosystem services are perceived as the most vulnerable, or which make the greatest contribution to human wellbeing. 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. It is generally used with an emphasis on individual perceptions (but collective preferences can be also gathered). Preference assessment is a useful approach for identifying relevant services from different stakeholder perspectives with diverging interest or needs. Its application can help to uncover differences and similarities in preferences between different social groups in terms of ecosystem service demands. In some cases, the different preferences between social actors and stakeholder groups fit the trade-offs and synergies of ecosystem services created by land-use management (Martin-López et al. 2012) because different stakeholders might be able to manage the landscape on the basis of their needs, interests and preferences (Nagendra et al., 2013).

Keywords

Individual value; Demand; Quantitative assessment; Questionnaire; Survey method; Social preference; Socio-cultural valuation.

Why would I chose this approach?

The motivation for using this method is the requirement to understand which services are in highest demand (or valued most) in a particular context (or the ones that are socially perceived as the most vulnerable). This approach could be helpful to address the following objectives:
- to demonstrate the social importance of ecosystem services,
- to set priorities within management strategies (e.g. working first on those services characterized as highly vulnerable but highly demanded) within the context of the ecological status of other ecosystem services (declining, stable or improving).
- to understand the multiple needs of different stakeholders and, in doing so, anticipate potential social conflicts derived from policy decisions affecting different ecosystem services.

It can be conducted using different survey options: (1) free-listing exercises where no previous information is provided and respondents are asked to name ecosystem services using an open ended question, (2) ranking or rating of ecosystem services on the basis of panels provided to respondents with some information (e.g. Castro et al., 2011; Martín-López et al., 2012); or (c) selection of ecosystem services that are the most important for respondents individual wellbeing or for social wellbeing from a pre-defined list of existing services in a given context (Oteros-Rozas et al. 2014).

Usually, supporting material is provided including pictures or examples. Additional questions can be useful to capture information on motivations or reasons behind the services selection.

When assessing collective preferences, a small group of participants debates and reaches a consensus-based value of the main ecosystem services in a particular area (Palomo et al. 2012). These surveys and workshops can also include information (qualitative or quantitative) regarding which services are the most important or vulnerable, the main trends in ecosystem service delivery, the drivers of change, or the spatial scale at which an ecosystem service is demanded (García-Nieto et al. 2015). In this template, we are going to focus mainly on the individual survey application.

Methodologically, the main challenge of individual preferences is related to the sample size required to collect representative information. The sample size should be representative of the population targeted in the analysis. This challenge is also reflected in other methods, such as photo-elicitation or time use.

Any ecosystem service could be assessed and valuated through this tool when the targeted respondents have a fairly good understanding of the services. In fact, a wide range of ecosystem services can be assessed at the same time. Information collected through preference assessment can be feed into awareness raising campaigns but can also be used to inform priority setting processes (with quantitative data) or instrument designs.

This approach is suitable to apply at any spatial scales if sample representation is guaranteed.

What are the main advantages of the approach?

- It assesses a range of ecosystem services at the same time, and could be used for all different service categories;
- It can provide robust quantitative information (from a representative sample) (Scholte et al. 2015);
- It avoids incommensurability issues resulting from the assignation of monetary value to service properties that cannot be monetarily measured (Martinez Alier et al. 1998; García-Llorente et al. 2011);
- The standardisation of the questions included could promote comparability with other case studies (e.g. Martín-López et al. 2012).

What are the constraints/limitations of the approach?

- Preference assessment captures a point in time, not a trend. In addition, sometimes, extra qualitative information is needed to understand the reasons behind the responses given;
- Key stakeholders can be ignored if the surveys focus on characteristics which are relevant for a very limited percentage of the population.
- Answers focused on the contribution of ecosystem service to an individual respondents' human wellbeing fails to take into account shared and social values of ecosystem services (Kenter et al. 2015). For a comparison between individual wellbeing and social wellbeing (i.e., shared and social values) by using this technique, see Oteros-Rozas et al. (2014).

What types of value can the approach help me understand?

Preference assessment is highly suitable to ascertain socio-cultural values, as it was originally designed for that purpose. It is useful for estimating the instrumental values of nature's benefits and how people might relate to nature through developing different activities (i.e. relational values). It is therefore suitable for estimating use and non-use values of nature and ecosystem services.

How does the approach address uncertainty?

The method aims at obtaining a representative sample of the population potentially affected. Multi-variate statistical methods can be used, which makes it possible to test whether variables explaining preference rankings/ratings are statistically significant.

How do I apply the approach?

The method requires 6 basic steps (see figure 1 below): (1) to target the ecosystem services in the valuation exercise, (2) to select the specific methodologies which can be adopted within the approach, e.g. restoration initiatives or conservation activities related with ecosystem services, (3) to identify the targeted population, (4) to design the questionnaire, (5) to conduct the survey, and (6) to analyze the WTT metric through econometric analyses.

For the questionnaire design, if researchers decide to present a list of ecosystem services to respondents, then it is essential to provide a suitable list of ecosystem services adapted for the case study context. It could be helpful to follow and adapt a recognized ecosystem service classifications such as the common international classification of ecosystem services (CICES; www.cices.eu) (Haines-Young and Potschin, 2013).

A pilot sampling is always recommended to improve the wording of the survey and adapt it to the case study context (e.g. particular ecosystem services, specific activities to invest time in, target population).

Methodological steps

Target ecosystem services and research interest

⬇

Methodological approach/es selection

⬇

Target population characteristics

⬇

Questionnaire content design

⬇

Field survey

⬇

Statistical analysis and reporting

Questionnaire content

Respondent knowledge and familiarity with the study area

⬇

Respondent relationship, attitudes and knowledge concerning the ecosystem services

⬇

Preference scenario

⬇

Environmental behavior characteristics

⬇

Socio-economic characteristics

⬇

Follow-up questions

Figure 1. The basic steps to be employed in Preference Assessment

Requirements

Requirements		Comments
Data	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) ☐ **Need to collect lots of new data (e.g. valuation based on surveys)**	This statement only refers to social surveys.
Type of data	☐ **Quantitative** ☐ **Qualitative**	Quantitative data is key, and qualitative data is recommended.
Expertise and production of knowledge	☐ **Working with researchers within your own field** ☐ **Working with researchers from other fields** ☐ Working of non-academic stakeholders	
Software	☐ **Freely available** ☐ **License required** ☐ **Advanced software knowledge required**	Software for statistical analysis is required; the particular software and its availability will depend on the researcher decision.
Time resources	☐ Short-term (less than 1 year) ☐ **Medium-term (1-2 years)**	Time requirements will vary in terms of the previous information compiled (literature review or interviews) and the techniques

	☐ Long-term (more than 2 years)	used (for example online surveys would be completed much faster than face-to-face questionnaires). Minimum of 9 months (questionnaire design, data gathering in field, and econometric analysis) could be established, till one or two years for a recommended situation. It is essential to ensure that respondents understand the exercise
Economic resources	☐ Low-demanding (less than 6 PMs) ☐ **Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	
Other requirements		

Where do I go for more information?

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Factsheet prepared by Marina Garcia Llorente and Berta Martin-López

METHOD FACTSHEET

Photo-elicitation method

Introduction

This method aims to translate people's visual experiences and perceptions of landscapes in terms of ecosystem services. Although it's main objective is to explore the links between landscape features and social perceptions of ecosystem services. It has been particularly used to explore how landscape multi-functionality (defined as the capacity of ecosystems to provide ecosystem services to society) is related to public perceptions toward landscapes and ecosystem services (García-Llorente et al., 2012). This is based on the idea that visual stimuli could be understood as a socially shared communication channel, providing the potential to identify and analyse social perceptions of ecosystem services (García-Llorente et al., 2012, López-Santiago et al. 2014). Respondents specify the principal ecosystem services provided by each landscape from a list of potential services provided by the area (in some cases, this step is not conducted during the questionnaires but through an expert focus group; see García-Llorente et al., 2012).

Keywords

Landscape appreciation; Multi-functionality; Photo-questionnaire; Scenic beauty; Visual perception.

Why would I chose this approach?

This approach is useful to identify individual preferences associated with landscape views. First, it helps to explore whether people appreciate different landscapes and how they are related to different ecosystem services. If pictures are geo-tagged, when focusing on specific services, it could help to reflect in a spatially explicit way (with mapping) the areas where those services are most appreciated (hotspots) (Nahuelhual et al. 2013). Other possible objectives for its applications are: (1) to particularly explore which aesthetic value of landscapes constitute cultural ecosystem services (García-Llorente et al. 2012); (2) to assess how perceptions change when a landscape intervention is conducted (e. g. afforestation plan, river restoration, etc.) (Petursdottir et al. 2013) and (3) to understand whether there is a correspondence (synergy) or spatial trade-off between the ecosystem services perceived as provided by a particular landscape and the actual demand (Casado-Arzuaga et al. 2014; Casalegno et al. 2013).

The main problems associated with this method are the ones related to carrying out surveys (see Preference Assessment method factsheet). This approach could be applied to any ecosystem service that can be illustrated pictorially. This is more challenging for regulating services, but is especially promising for cultural ecosystem services (particularly aesthetic and existence values (García-Llorente et al. 2012).

The use of the approach depends on the decision context to which it has been applied, but it can be used for; 1) awareness raising, 2) to inform priority setting processes (hot spot analysis) and for 3) instrument design through the identification of the areas where specific ecosystem services are

supplied and the identification of the human settlements where there is a high demand for such services.

This approach has been applied at project, county and regional scales, although is also suitable at national scales where different landscape units can be distinguished. It is worthy to note here that the higher the scale the more generic the photo-description of the ecosystem services. At the scale of the individual it can be very detailed (100 m^2 – 1 ha), but this highly resolved data can also be aggregated into larger spatial units (Nahuelhual et al. 2013).

What are the main advantages of the approach?

- Easy to understand and very dynamic, as long as respondents are receptive to its application;
- Can be used to assess a range of landscape views at the same time;
- It makes it possible to connect landscape views with ecosystem services or with more general landscape characteristics such as land-use patterns;
- Suitable to assess cultural services across a range of value types (e.g. spiritual, heritage, aesthetic);
- Results can help to identify potential conflicts between social groups through exploring the differences between stakeholders coming from different environments (e.g. rural-urban gradient).

What are the constraints/limitations of the approach?

- Some ecosystem services are not easily linked to the landscape views, being less visually evident (e.g. some regulating services);
- Photos only show a limited and framed view of the surrounding, captured at a specific moment in time (Petursdottir et al. 2013);
- In some cases, participants learn about ecosystem services during the interview or questionnaire. This 'learning happened' should be taken into account when interpreting results;
- Problems of generalisation with scale. It is important to have in mind that the higher scale, the more generic the photo description of the ecosystem services.

What types of value can the approach help me understand?

This method is suitable for uncovering and estimating socio-cultural values in quantitative and qualitative terms. It is suitable for exploring ecological values through the analysis of landscape features connected with different ecosystem services, particularly valued for the aesthetic appreciation of landscapes. It can also be used to estimate the instrumental values of nature's benefits (i.e. both use and non-use values of nature and ecosystem services).

How does the approach address uncertainty?

The method has limited ability to address uncertainty.

How do I apply the approach?

The data collection is required at different steps (see figure 1. below): (1) Identification of landscape units and selection of landscape views (and photographs) that are representative of the land units; (2) Photographs of the landscape views should maintain similar characteristics (e.g. constant weather, similar % of visible sky, etc.) to avoid biases; (3) Landscape views represented in pictures are ranked into levels (for example from 1= "do not like at all" to 5= "like very much"), according to how attractive participants find each picture (other criteria could be used); (4) Identification of main services provided by landscapes: respondents are asked to assess the degree of ecosystem services delivery by the different landscapes. In other cases, this latter step is not conducted during the questionnaires but through an expert focus group (see García-Llorente et al., 2012).


Figure 1. Methodological steps taken in a photo-elicitation survey related with preferences towards landscape views (based on García-Llorente et al., 2012). Not all the steps would need to be considered in an exercise, being stage 1 the key one. Landscape views relation with ecosystem services or with land uses are just potential complementary questions that could be assessed through other vehicles.

Requirements

Requirements		Comments
Data	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) ☑ **Need to collect lots of new data (e.g. valuation based on surveys)**	
Type of data	☑ **Quantitative** ☐ Qualitative	Quantitative data is key, and qualitative data is recommended.
Expertise and production of knowledge	☑ **Working with researchers within your own field** ☑ **Working with researchers from other fields** ☐ Working of non-academic stakeholders	Working with researchers within your own field is required, including other fields is highly recommended. Non-academic stakeholders are the source of data gathering, however usually they do not participate in the data interpretation.
Software	☑ **Freely available** ☑ **License required** ☑ **Advanced software knowledge required**	Statistical software is recommend to enrich the analysis performed.
Time resources	☐ Short-term (less than 1 year) ☑ **Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	Time required involve a minimum of 12 months (selection of landscape views, questionnaire design, data gathering in field, data analysis).
Economic resources	☐ Low-demanding (less than 6 PMs) ☑ **Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	
Other requirements	-	

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Factsheet prepared by Marina Garcia Llorente and Berta Martin-López

Ecosystem service card game

Introduction

The ecosystem services card game is a method developed to capture the sociocultural values related to ecosystem services. This method specifically focuses on exploring and understanding human preferences and perceptions of ecosystem services. This makes it a useful tool for assessing landscapes that provide various direct benefits to individuals, especially cultural landscapes which have been shaped by long-term human impacts and which are frequent targets of human use and enjoyment.

The ecosystem services card game method combines photo-elicitation with a rating exercise. It serves a double purpose: on one hand it encourages interviewees to discuss why an ecosystem services is important to him/her and thus provides qualitative information, on the other hand, by rating ecosystem services according to usefulness, importance or other locally relevant factors, a quantitative ranking of ecosystem services by order of importance can be obtained (Fontaine et al., 2013).

Keywords

Ecosystem services; Sociocultural valuation; Photo-elicitation; Ranking method.

Why would I chose this approach?

The card game is a method to rate ecosystem services according to their importance, and then compare their rating to obtain their relative values (i.e. define the importance of one ecosystem service in comparison with others'). The method can be used to answer different research questions:

1. Description of the area: Which ecosystem services are currently present in the study area?
2. Vision development: Which ecosystem services are desirable for the future?
3. Identification of ecosystem service stakeholders: Which stakeholders are involved in the regulation, management, use and enjoyment of ecosystem services provided by the area?

This method can be used to collect knowledge and opinions about a wide range of ecosystem services, as well as to understand preferences for these ecosystem services. It is suitable to characterize provisioning and cultural services from the point of view of stakeholders, but regulating services are sometimes undervalued if stakeholder knowledge is limited on these topics.

The method is suitable to awareness raising as it can highlight a wide range of benefits and values attached to ecosystem services. It can also be used as a supporting tool for priority setting, as the rating and comparison of ecosystem services leads to a priority list of locally relevant ecosystem services which then can be serve as a basis for land use planning. The card game also provides information on the preferences and motivations of different stakeholder groups (including different

groups of users), which can be used as an input to instrument design (i.e. when developing access/restriction rules for recreational areas).

The method can be easily applied at smaller spatial scales (from property to municipality or county level). Applying it to larger spatial scales is also possible (depending on the framing of the questions and the list of ecosystem services used in the exercise), but might be slightly more difficult because interviewees usually have less personal experiences with ecosystem services at larger scales. Spatial scale should match the knowledge of the interviewed people. The spatial resolution offered by the method is rather coarse.

What are the main advantages of the approach?

- Relatively simple and quick;
- Card sets can be tailor-made according to specific situations;
- Includes local knowledge;
- Stimulates stakeholders to think within a holistic ecosystem services framework ("social learning").

What are the constraints/limitations of the approach?

- Good interview skills are indispensable;
- Not all classes of ecosystem services might be appropriately valued when valuation methods using stakeholder preference are used (Agbenyega et al., 2009; Carpenter et al., 2006). It is suitable to characterize provisioning and cultural services from the point of view of stakeholders, but regulating services are sometimes undervalued if stakeholder knowledge is limited on these topics.
- It is important to keep in mind that the card game only values perceptions of stakeholders;
- Trade-offs between the actual use of services and the use of services in the future are not accounted for (intergenerational trade-offs);
- Working with a predefined list of ecosystem services has a framing effect on the results (i.e. it restricts the potential list of ecosystem services if there is no option to add new services during the game).

What types of value can the approach help me understand?

The card game is especially suitable to elicit socio-cultural and anthropocentric (both instrumental and relational) values to ecosystem services. It has limitations to grasp indirect use values, option values and ecological values.

How does the approach address uncertainty?

Uncertainty can be captured in narrative ways.

How do I apply the approach?

As a preliminary step of the card game, relevant ecosystem services (that are presented on the cards) are selected based on expert knowledge and scientific information. To this end, reviews of

scientific literature and expert interviews can be conducted. The actual steps followed during the card game are presented in Figure 1.

Figure 1. Steps in the use of the ES Card game

| Open interview | The interviewer asks questions about how the respondent uses the area without the "restriction" of cards. |

| Ranking the cards | The cards with the individual ESS are shown one by one. The respondent is asked to rate the cards according to 6 categories. "++", "+" "0", "-", "- -" or "I don't know". |

| Interviewing the cards | The respondent explains why (s)he rated the cards in a certain and tells more about the link between these ESS and the area. |

| Identifying the most important cards | Extra columns "+++" and "- - -" are added. The respondent is asked to choose the most important cards from the "++" category and the most disturbing cards from the "- - " category to put them in the new categories and asked to justify her/his selection. |

| Processing results | The valuation of different respondents can be added for each ESS and shown in a graph. The arguments supporting consensus or contrasts told during the interviews, can be structured and analysed in word processing software, or in specific software, e.g. NVivo. Results give an overview of the degree of consensus and/or contrasting views on the valuation of the different services. |

Requirements

Requirements		Comments
Data	□ Data is available □ **Need to collect some new data (e.g. participatory valuation)** □ Need to collect lots of new data (e.g. valuation based on surveys)	Data is collected through in-depth face-to-face interviews or group discussions (lasting approx. 60-90 minutes). The ideal number of interviews/group discussions depends on the heterogeneity of stakeholders and the size of the research area. As a rule of thumb, each key stakeholder group should be represented by at least 2-4 representatives in the sample. In average, the number of interviewees ranges between 20-25 people.
Type of data	□ **Quantitative** □ **Qualitative**	The method elicits both quantitative (rating and ranking the cards representing different ESs) and qualitative (narrative explanation of the cards) information.
Expertise and production of knowledge	□ Working with researchers within your own field □ **Working with researchers from other fields** □ **Working with non-academic stakeholders**	The interviewing phase requires social scientific skills and expertise, while the choice of ESs to be ranked can be based on ecological expertise and local use expertise. Non-academic stake-holders are involved through the interviews.
Software	□ **Freely available**	The valuation of different respondents can be presented in a graph with a spreadsheet

		application. The arguments mentioned during the interviews, can be structured and analysed in word processing software, or in specific software, e.g. NVivo
Time resources	☐ **Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Average number of interviews is around 20-25 (depends on the heterogeneity of stakeholders), average length of interviews ranges between 60-90 minutes.
Economic resources	☐ **Low-demanding (less than 6 PMs)** ☐ Medium-demanding (6-12 PMs) ☐ High-demanding (more than 12 PMs)	Both time requirements and economic resources depends on how many participants are involved in the valuation study. If only a small sample (<25) is used, less than 6 PMs can be enough.
Other requirements	-	

Where do I go for more information?

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Factsheet prepared by Rolinde Demeyer and Francis Turkelboom

Eco Chain Participatory Biodiversity Management

Introduction

Perennial flows of natural capital such as biological resources, water and clean air are essential for achieving sustainable development for well-being. Disruption of ecosystems and the decline of ES are often caused by over-exploitation of biological resources. Without accountable public governance, compatible with the appropriate social institutions, no 'Scientific Theory' or 'Policy' will be effective (Roy & Mukhopadhyay, 2015). Approaches where the community and government functionaries work together in 'Participatory Biodiversity Monitoring and Management' are more likely to be successful.

Eco Chain is an approach to raise the awareness of local people with respect to the interdependence and relationships between different components of ecosystems in a given landscape which are interconnected like a chain, i.e. it is necessary to maintain biodiversity to preserve its associated ES. The approach aims to motivate people to conserve habitats and biodiversity through the process of Participatory Biodiversity Management. This blends scientific principles with indigenous knowledge and includes participation of the stakeholders in:

1. Identifying the problems;
2. Assessing the available resources and trade-offs;
3. Setting the goals; and
4. Developing action plans to reach the goals.

Keywords

Participatory methodology; Governance; Stakeholder engagement; Local and indigenous knowledge

Why would I chose this approach?

The method effectively involves local communities in finding solutions to arrest ecosystem degradation such as deforestation, which has its primary immediate negative impact on the indigenous local community themselves. It encourages local communities to spontaneously take responsibility to act and to monitor progress. Furthermore, including indigenous knowledge helps to build synergies between different approaches for conservation.

Finally, the approach has been shown to work and the Joint Forest Management program in India shows highly encouraging results in terms of checking deforestation through community participation. Through collaborative work between the community and forest field staff within the Indian Institute of Bio-Social Research and Development (IBRAD), simple yet scientific criteria and indicators were developed, as well as a template and checklist that can be used to diagnose forest

degradation. Further work is expected to illustrate how the data collected are used to take up possible corrective action to improve ES through a cascading effect.

What are the main advantages of the approach?

- The approach provides information to support conservation strategy decision-making jointly between government agencies and the local community;
- The approach helps to prepare participatory plans for sustainable harvesting of biodiversity in a way that balances economic benefits for the community with the conservation of biodiversity and improved flow of ES.

What are the constraints/limitations of the approach?

- It is difficult to make the community aware of the implications of loss of biodiversity and decline of ES and to develop their own social norms to restrict the overharvesting of timber and other forest products;
- It is difficult to have a strategy for long-term community level planning unless they are trained appropriately in Participatory Biodiversity Monitoring and skill development for livelihood improvement based on available natural resources;
- It is difficult to involve the public forest field staff as they have little faith in the application of traditional knowledge.

What types of value can the approach help me understand?

The approach is designed to raise awareness of the multiple values provided by the natural environment. It is particularly good for identifying locally important ecosystem services and socio-cultural values associated with these.

How does the approach address uncertainty?

The approach does not explicitly address uncertainty.

How do I apply the approach?

The key to the entire approach is the identification of proactive leaders and raising awareness and engagement within the community to monitor drivers of degradation by developing effective social institutions. The local community and local government staff need to work together to conserve the ecosystem as a social movement, instead of as a project based on externally directed activities (Roy, 1996). To follow the Eco Chain approach it is necessary to have some trained staff, preferably with a social science background, who would work with the community and the local officials. Before conducting the session at the village level it is necessary to inform local officials and community leaders about the approach. An awareness-raising session is then organised in the village. The inclusion of different stakeholder groups is encouraged for collective social action for conservation. Conscious effort is made to involve women and other groups engaged in livelihoods that are dependent on biological resources.

A large photograph/banner with a map of the local area is created to demonstrate the current status of the forest ecosystem. This is used during the introductory session to facilitate discussion, and to make people understand the spatial distribution of different ecosystems in the area. It also stimulates the thought processes of the local people to understand the status and forces of degradation and the corrective actions that may need to be taken.

After the first awareness-raising session, the next step is to prepare inventories to assess the status of biodiversity, both species and genetic diversity, as well as their threat status. This is done by laying out quadrats on sample plots (normally 1% of the forest area is covered by laying the grids on the topographic sheet maps) that are georeferenced with GPS readings. This requires quadrats, GPS, measuring tapes, coloured paint and paint brushes.

The criteria to assess the degree of deforestation and biodiversity loss and understand the health of a given habitat, developed by involving the forest community, are the degree of forest cover fragmentation, standing biomass assessments, canopy cover, species richness, and quality of soil and water. The Eco Chain approach was developed for the two forest protection committees of Jamkanali and Jamirdiha of the Bankura district of West Bengal, India to assess their forest status and biodiversity, but the approach can be replicated elsewhere. An overview of the process is as follows:

Stage 1: Initial awareness-raising meeting
The first step is to raise awareness of the benefits the community will derive when their own ecosystem and its habitats are well conserved. A meeting is organised at which the forest staff and the community work together on visualising this and also on delineating their immediate loss, if the ecosystem is not conserved by their own efforts.   The following sub-steps are followed during this awareness-raising stage:

- Conduct a meeting with community, local officials and local self-government staff in the village itself.
- After introduction, show them the map and landscape (e.g. using freely available Google Earth images).
- Brainstorm with the participants to identify different components of the ecosystems such as forest, water bodies, agricultural field, grasslands, etc. in the designated landscape.
- Ask the participants about the relationships between these components.
- Make a list of interactions between the different components and ask them to write on the chart about the result of interactions (e.g. what happens when one component, say water, interacts with others like grassland, forest, etc.)
- On the chart write five items: i) Water ii) Forest iii) Agricultural fields iv) Animals and v) Humans and ask them three key questions:
  - i. Which one of the components do the villagers not require for their survival;
  - ii. How are these components inter-related and inter-dependent;
  - iii. How can these components of the ecosystem be protected.

- After writing the answers though group discussion, each group presents their findings and (if appropriate with the particular stakeholder group) the best one can be awarded and recognised.

Stage 2: Institution building

After the presentation, volunteers are identified from among the group as proactive leaders who recognise the value of conserving the benefits from biodiversity. These leaders are tasked with forming a group of volunteers of like-minded people to work with the local government functionaries on Participatory Biodiversity Management. The drivers of degradation are then identified though participatory rural appraisal. The drivers are then ranked and the community are asked to identify solutions.

Stage 3: Diagnosis of status of health of the habitat and recording of baseline data by developing participatory criteria and indicators by involving the community

To assess the status of the habitat and develop a baseline, participatory transect walks and baseline surveys are performed for each unit of sub-ecosystems (e.g. freshwater, agricultural ecosystem, and the forest and its varied components). Baseline data should be collected on the nature and degree of degradation based on the following six criteria:

(i) The **degree of fragmentation**: This can be assessed by drawing a transect line on the map in the forest and walking the transect with the community. Community discussion about the degree of fragmentation is encouraged. Remote sensing maps can also be used to quantify the degree of fragmentation. Fragmentation of the forest can also be marked by community members using GPS.

(ii) **Canopy openness in the forest understorey is minimised**: Identify the canopy density of the forest by involving the community.

(iii) **Species guild structure**: Identify terrestrial, avifauna and aquatic species within the forest quadrat by involving the community following the quadrat method and laying sample plots. The community oversees how the abundance of insects, avian guilds and fruiting intensity in well-pollinated tree species is maintained.

(iv) Identification of **REET[14] and keystone Species**: Identification of flagship species and keystone species of the area are identified by consulting the community. They are also asked (a) which species are becoming rare, extinct, threatened at the local level and (b) how those species can best be restored (i.e. what kind of corrective plan of action is needed). Species abundance data can be collected for use as an indicator for monitoring the effects and effectiveness of forest management. The process helps members of the community appreciate the diminishing rate of provisioning ES.

(v) **Soil structure, quality, moisture and rate of decomposition:** Discuss with the community about the status of soil, soil health and status of soil degradation and prepare plan of action on how to reduce overuse of chemical fertilisers to restore the soil health.

(vi) **Water condition**: Identify the water bodies and their status of degradation and plan for conservation through rainwater harvesting and other measures. All-season water levels in rivers and streams are a key indicator in this context and may indicate if sufficient forest cover remains to regulate flows, especially in dry seasons.

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[14] Rare, extinct, endangered or threatened

Stage 4: Develop conservation action plans

Action plans for conservation, eco-restoration and enhancing productivity are developed in consultation with the teams. These may include:

- Scientific management of land and rainwater such as in-situ moisture conservation, introduction of scientific production systems, network of run-off management structures;
- Developing a strategy for recharging of groundwater;
- Considering mechanisms for in-situ and ex-situ conservation of biodiversity;
- Organise trait-based training for livelihood development.

Stage 5: Equitable benefit sharing plans

The final stage involves working with the community to plan actions for equitable benefit sharing and building this into the conservation action plans.

Requirements

Data	☑ Data is available ☑ Need to collect some new data ☐ Need to collect lots of new data	Maps can be downloaded from Google Earth, threat can be assessed following Red Lists.
Type of data	☑ Qualitative ☑ Quantitative	Forest density and diversity, fragmentation status, water and soil condition, people's institutional mechanisms.
Expertise and production of knowledge	☑ Work with researchers within your own field ☑ Work with researchers from other fields ☑ Work with non-academic stakeholders	Different stakeholders would discuss the interdependence of ecosystems following the map and transect walk. Other methods such as group discussions are integrated to involve the people in understanding the interdependence between social and psycho-cultural aspects.
Software	☑ Freely available ☐ Software licence required ☐ Advanced software knowledge required	
Time resources	☐ Short-term (< 1 year) ☐ Medium-term (1-2 years) ☑ Long-term (more than 2 years)	
Economic resources	☑< 6 person-months ☐ 6-12 person-months ☐> 12 person-months	
Other requirements		

Where do I go for more information?

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Factsheet prepared by S. B. Roy & Raktima Mukhopadhay

Time use studies

Introduction

Time use study is an innovation of the conventional stated preference techniques taken from the contingent valuation approach. In this case, the payment vehicle is expressed in labour hours rather than monetary units (as used in the classical willingness to pay studies) (Kenter et al. 2011). Willingness to give up time (WTT) creates a hypothetical scenario using surveys to estimate the value of ecosystem services by directly asking people how much time they would be willing to invest for a change in the quantity or quality of a given ecosystem service or conservation (or restoration) plan. Besides being an appropriate approach in scenarios where people can invest time for particular activities related to nature; this approach is also useful in areas with income constrains where money is basically used for essential goods (Higuera et al. 2012). It also avoids issues resulting from the assignation of monetary value to ecosystem service properties that cannot be monetarily measured (García-Llorente et al. 2011).

Keywords

Income constrains; Rural areas; Social preferences; Social Value, Willingness to give up time

Why would I chose this approach?

The general purpose of time use studies is to capture the willingness to give up time (WTT) per individual to different ecosystem services. This technique is able to estimate the value of multiple ecosystem services (provisioning, regulating and cultural) through depicting scenarios which entail their restoration, management or conservation. It is also able to capture the social factors that determine social preferences.

In general, the main outputs obtained from its application are:

1. The WTT per ecosystem service to understand social demands and priorities for services conservation.
2. The socio-cultural factors or motivations influencing individual decisions around being willing to give up time.
3. A new indicator to measure social support towards conservation.
4. The economic value of ecosystem services though the translation of willingness to give up time into monetary units, multiplying stated WTT (in hours/month) by net income per month (Euros/month) expressed by each individual during the questionnaire (these values can even be aggregated).

These methods have been applied to a range of decision contexts, including: awareness raising and priority setting. It has been applied at county scales at the level of individuals, however the relevant spatial resolution is primarily determined by the specific service measured.

What are the main advantages of the approach?

- Useful in contexts where severe income constrains makes WTP studies inappropriate (Higuera et al., 2012; Kenter et al., 2011);
- Avoids incommensurability issues resulted from the assignation of monetary value to service properties that cannot be monetarily measured (e.g. García-Llorente et al., 2011);
- Can be used to assess a range of ecosystem services at the same time, and to estimate the importance people attach to biodiversity in general (García-Llorente et al., 2016);
- When activities are well-defined, respondents do not need to have a fairly good understanding of the delivery of ecosystem services because this link can be done at a later time by researchers;
- WTT can be understood as a holistic indicator of human time-sharing initiatives in nature and, thereby, it is able to raise awareness about our ability to harmonize our lifestyles with the rhythms of nature (García-Llorente et al. 2016);
- Beyond the estimation of the value of ecosystem services through the WTT; its development can engage stakeholders with environmental activities, increase collaboration, social learning and knowledge co-generation (Higuera et al. 2012; García-Llorente et al. 2016).

What are the constraints/limitations of the approach?

- WTT is unsuitable for application to cases in which the respondents have little time availability;
- Modeling WTT processes requires the inclusion of time available as an explanatory variable. Therefore, a daily time analysis should be included in the questionnaire, which is however time consuming and often tiring for respondents;
- Classical methodological biases from conventional stated preference methods can occur;
- It is important to provide a clear description of the activities (and how they relate to ecosystem services) in which time could be invested in the hypothetical scenario. If not, the activities might be selected because of respondents' preconceived ideas or because of the physical effort required for performing them.

What types of value can the approach help me understand?

This method is suitable for uncovering and estimating socio-cultural values in quantitative terms. It is also useful for estimating the instrumental values of nature's benefits and how people might relate to nature through developing different activities (i.e. relational values). It can be also suitable for estimating use and non-use values of nature and ecosystem services.

How does the approach address uncertainty?

The method aims at obtaining a representative sample of the population potentially affected. It generates a probability distribution of willingness-to-give up time for the population, which can be used to calculate confidence intervals. Multi-variate statistical methods can be used, which makes it possible to test whether variables explaining willingness-to-give up time are statistically significant.

How do I apply the approach?

The method requires 6 basic steps as indicated in Figure 1: (1) to target the ecosystem services in the valuation exercise, (2) to select the specific methodologies which can be adopted within the approach, e.g. restoration initiatives or conservation activities related with ecosystem services, (3) to identify the targeted population, (4) to design the questionnaire, (5) to conduct the survey, and (6) to analyze the WTT metric through econometric analyses.
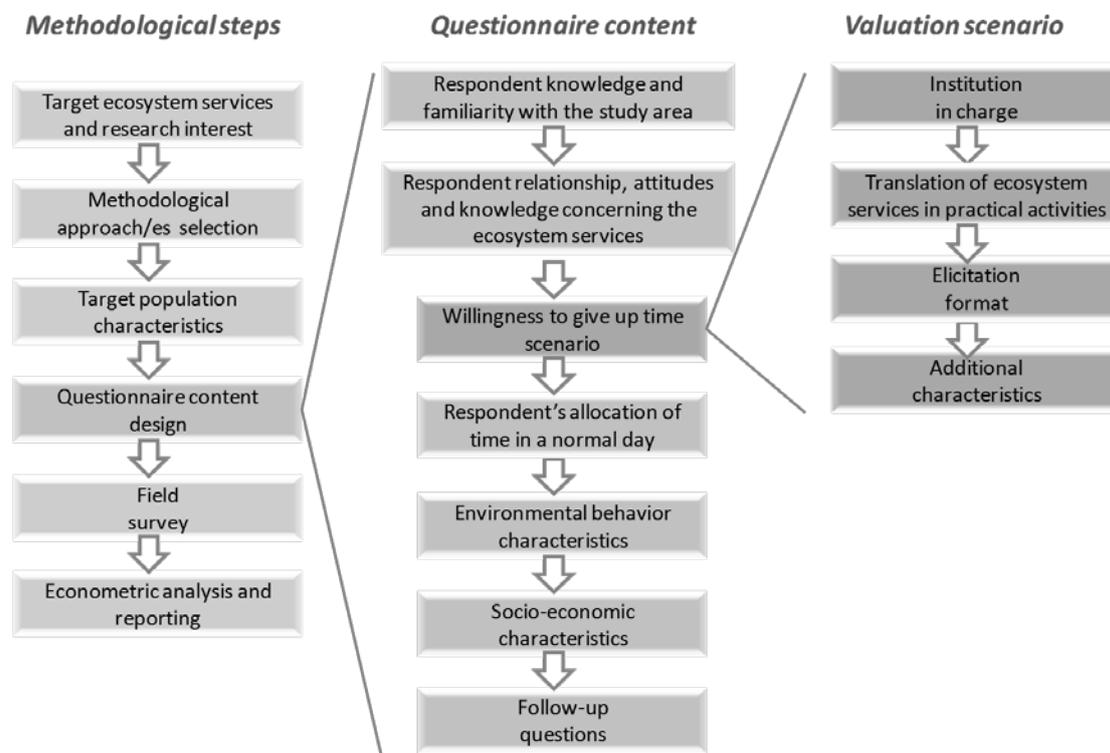

Figure 1. The basic steps to be employed in Time use studies.

Requirements

Requirements		Comments
Data	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) ☐ **Need to collect lots of new data (e.g. valuation based on surveys)**	
Type of data	☐ **Quantitative** ☐ Qualitative	
Expertise and production of knowledge	☐ **Working with researchers within your own field** ☐ Working with researchers from other fields ☐ **Working with non-academic stakeholders**	
Software	☐ **Freely available** ☐ **License required** ☐ **Advanced software knowledge required**	The software requirement will depend on the case and the scientists' skills.

Time resources	☐ Short-term (less than 1 year) ☑ **Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	
Economic resources	☐ Low-demanding (less than 6 PMs) ☑ **Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	
Other requirements	Statistical knowledge and econometric modelling skills could be needed	

Where do I go for more information?

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Factsheet prepared by Marina Garcia Llorente and Berta Martin-López

MONETARY METHODS

Value transfer method

Introduction

Benefits transfer (BT), or more generally - value transfer (VT) - refers to applying quantitative estimates of ecosystem service values from existing studies to another context. Value estimates from one 'study site' can be applied with adjustments to a 'policy site' where time or resource constraints preclude the possibility of doing a primary valuation study at that site. In the VT literature values have generally been understood to be monetary estimates of benefits or costs (Johnston et al., 2015). Often VT is used for screening in a benefit-cost analysis of project or policy alternatives. Value transfer is not one specific method, but a continuum of the following approaches depending on the information available:

- **Unit value transfer:** Value estimates are assumed to be correct 'on average' and transferred without any form of adjustment.
- **Adjusted unit value transfer:** Value estimates are transferred with simple adjustments typically for study and policy site differences in income and purchasing power.
- **Value function transfer**: Significant predictors at the study site of willingness-to-pay typically (from contingent valuation or choice experiment studies), are identified at the policy site. The average value of predictors at the 'policy site' are then 'plugged into' the 'study site' value-function to derive an adjusted WTP figure for the policy site.
- **Meta-analytic function transfer**: Similar to value function transfer, but the value function is generated from a meta-analysis of many valuation study sites instead of a single study site. The method assumes that there is a meta-value function (i.e. similar preferences) that apply across all the study sites.

Although 'value transfer' is generally reserved for monetary estimates, there is nothing in principle against transferring non-monetary estimates of the benefits of ES, such as the ranking of ecosystem services, from a study site to a policy site.

Keywords

Benefits transfer; Value transfer; Screening; Benefit-cost analysis; Uncertainty; Study site; Policy site.

Why would I chose this approach?

Value transfer is necessary when a decision context calls for monetary estimation of ecosystem services, but time and resources are insufficient to carry out a primary study on-site. VT can be applied to all types of ecosystem services, as long as monetary valuation is considered a valid basis for decision-making. If you believe that people hold pre-formed preferences for spending on the environment, and these preferences are quite stable across decision-context – you are likely to be more inclined to accept VT.

What are the main advantages of the approach?

Methodological advantages
- Ease of use, available valuation databases;

- Draws on existing data;
- Low cost.

Governance advantages
- Speed of use.

What are the constraints/limitations of the approach?

Methodological constraints
- Potential ease of misuse;
- Transfer errors cannot be predicted (but can be inferred from similar cases);
- Not participatory;
- Uncertainty of transferred assessment often not assessed (see table A1 appendix);
- existing valuation studies often do not provide site context
- 'Context free' average values rather than context specific marginal values often employed.

Constraints in **governance**
- Decision-makers will often not know their own requirements for statistical reliability of valuation estimates;
- Insufficient benchmarking of cost uncertainty (as a basis for assessing acceptability of benefit uncertainty;
- Lacking credibility when on-site information is not used.

What types of value can the approach help me understand?

Monetary valuation methods have been applied to ecosystem services with many types of values. Value transfer applies to monetary valuation methods in general, across value types. The distinguishing feature is not the value type, but the reliability and accuracy requirements of the decision-context. Value transfer is inappropriate in cases where monetary value estimates are deemed unacceptable by constituencies and their representatives. Suitability will therefore vary from constituency/context to context.

How does the approach address uncertainty?

Are value transfer errors expected to be 'too large' relative to reliability required by the decision-maker? A benchmark is the level of confidence with which decision-makers require uncertain benefits to exceed uncertain costs of the policy/project. This will depend on the importance of the decision. For example, a routine decision with little conflict potential may be made if expected net benefits are positive with 90% confidence, while a conflictive decision may require expected benefits to exceed costs by several multiples in order to convince political opposition. VT can in principle be applied to any decision context (Figure 1), but the more a context requires reliable and accurate monetary valuation estimates, the less likely value transfer will serve the context purpose.
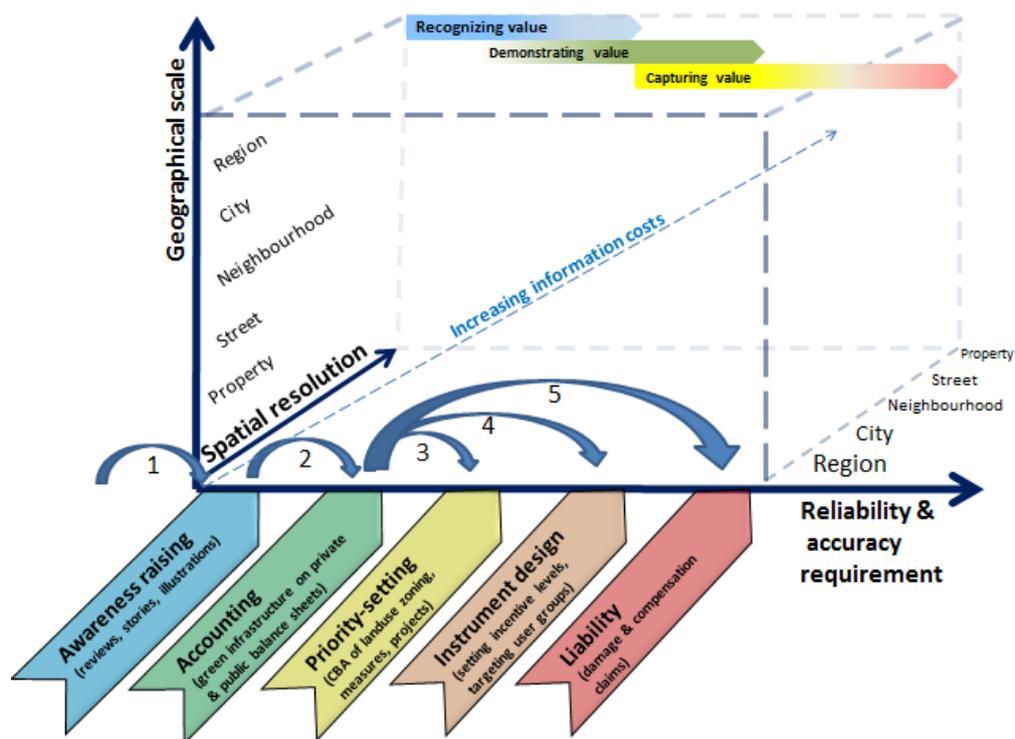
Figure 1. Value transfer is a stepwise updating of values for different contexts. Value transfer might start with the purpose of simple awareness-raising (1) and then get updated with new studies on-site information for more demanding decision contexts (2-5). Source: adapted from Gómez-Baggethun and Barton (2013)

Monetary value transfer is well known for its use in public *awareness raising* about the total economic value of natural capital, e.g. Braat and ten Brink (2008). In experimental ecosystem *accounting* (Obst et al., 2015), where monetary estimates must be applied across a landscape, some form of spatial extrapolation is needed - value transfer is also used here. As we move to *priority-setting* using benefit-cost analysis of projects in specific locations, requirements for on-site studies are likely to increase. Using valuation for setting incentive levels for specific stakeholders in policy instrument design, has even higher reliability requirements. Finally, liability for natural resource damage that occurred at a specific time and place, may be the most demanding and therefore the least appropriate context for value transfer. Because information costs increase with spatial resolution (figure 1), value transfer for awareness raising (1) or accounting (2) can be updated with progressively more site-specific information as the needs of decision-contexts require. For example, value function and meta-analytic function transfer include data on policy site characteristics such as demographics, accessibility and size of area which can be used to adjust original estimates.

All valuation of ecosystem services has at least some element of value transfer when estimates are applied to specific decision contexts (because each decision context is unique and therefore not identical to the decision context in which the ecosystem service values were generated in the original study).

How do I apply the approach?

The flowchart below provides a short description of the generic steps used in spatially explicit value transfer. Value transfer is embedded in decision analysis.   A more detailed decision-tree for using VT for screening in benefit-cost analysis can be found in Table 1.
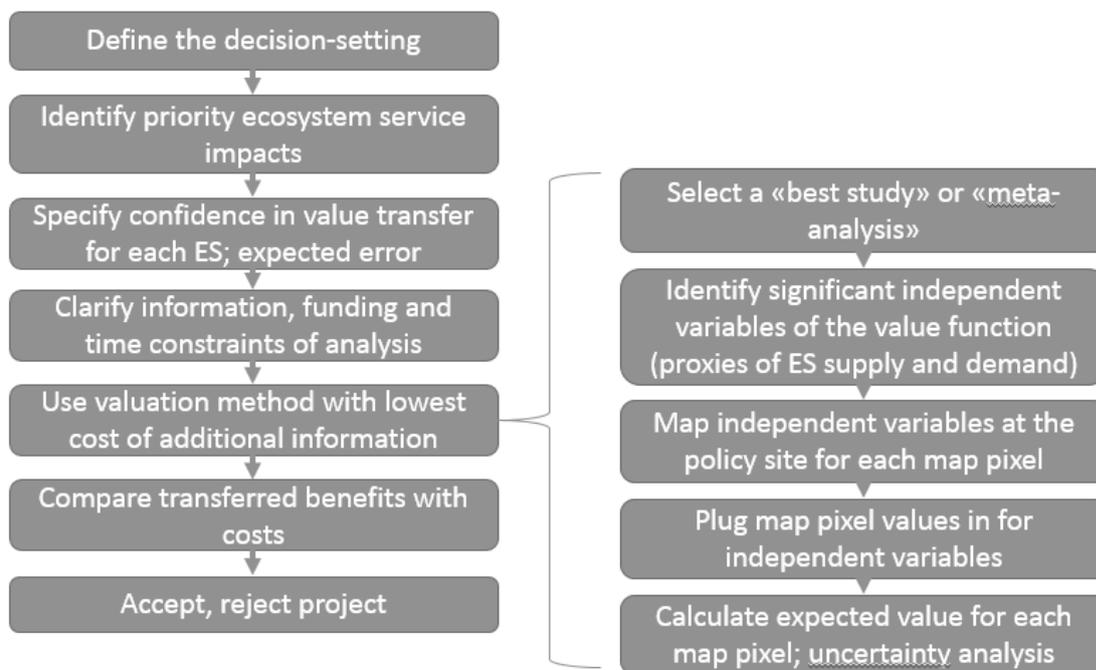

Figure 2. Stepwise process of value transfer

Some basic knowledge of potential errors is useful when reviewing value transfer studies. Awareness of the reliability of value transfer will make it clearer whether transferred values can be used for more demanding contexts such as priority-setting. Decision-makers can go through a check-list when assessing valuation results they have commissioned (Table 1, Figure 3).

Table 1. Value transfer checklist

Issue	Explanation
1. Marginal vs. average values?	If the purpose of the valuation is to inform a policy decision affecting a particular area the study should be sensitive to changing marginal values across the landscape. For simple informative uses such as awareness raising or natural capital accounting average values r be adequate.
2. Substitutes or complements?	Has the study considered the landscape configuration of green infrastructure and wheth particular sites are substitutes or complements for oneanother in terms of ecosystem services delivery?
3. Aggregation, distance decay?	Does the value transfer make any particular assumptions about accessibility and potentia user populations which may change across sites?
4. Distributional impacts and selection bias?	Is it important how costs and benefits are distributed spatially, for example because ther are different socio-economic constituencies in the study area? Spatially differentiated transfers are necessary. Check that population characteristics in the original study site co the range of characteristics at the policy site.
5. Equivalence of positive and negative impacts?	Is the value estimate at the study site generated for the same kind of environmental char as at the policy site? Research has shown that willingness-to-pay for an improvement in ecosystem services, c differ from WTP to avoid a loss, which in turn can be different from willingness-to-accept (WTA) compensation for a loss, or WTA compensation for not obtaining an improvement
6. Reference levels and perceived rights?	In addition to the +/- direction of the impact on ES, the perception of rights to a referenc level of ES determine values. The difference in WTP and WTA is in part explained by differences in the perception of rights to a particular reference level of ecosystem service the perception of environmental rights varies between the study and policy site there is further bias.
7. Adaptive behaviour?	If populations at a study and policy site adapt differently to an impact on ecosystem serv valuation can be expected to differ as well. Adaptive behaviour may mitigate realised impact. This also produces a difference between ex ante valuation estimates and actual change in welfare which is a common challenge in all economic benefit-cost analysis.
8. Compatible end-points?	Is the economic valuation estimate expressed in similar units to biophysical models quantifying the 'end-point' impact. This concerns the extent to which models in the ecosystem service cascade or cause-effect chain are well integrated. Making model end-points compatible often involves expert judgement and introduces uncertainty in the integrated valuation estimate.
9. Ad hoc variables?	More generally are variables in a meta-analysis function or value function theoretical justified or do they appear ad hoc?
10. Docu-mentation of uncertainty?	If the original valuation studies document statistical accuracy and model reliability using sensitivity analysis, more rational decision-making approaches can be taken as illustrated Figure 13 above.

Source: based on Barton (1999)

Design analysis:

Decision analysis:

Technical project/policy design

Clarify decision-setting
(Screening, BCA)

Pricing, NRDA

Primary valuation or polical/legal negotiation?

Environmental assessment

Clarify priority environmental impacts

Calculate opportunity costs of implementation (c)

Specify confidence in benefit transfer for identified impacts:
Specify Expected Error ($E^{+/-}$)
as a +/- % of c

high E

Adopt a different decision criterion? (e.g.CEA)

low E

Clarify constraints on benefit transfer:
Required Information$_t$ > AI_t ?
Required Funds$_t$ > AF_t ?
Required Time$_t$ > AT_t ?

$RF_t > AF_t$
$RT_t > AT_t$

$RF_t < AF_t$ $RT_t < AT_t$

Non-market valuation "toolkit":
1. Ad hoc "best" study approaches
2. Meta-analysis
3. Benefit function transfer
4. Primary non-market valuation study on site

Use valuation method with lowest cost of additional information:
(1) benefit transfer methods ($w^{p|s}$)
(2) primary valuation methods ($w^{s|s}$)

Screening:
$E^{+/-} = (w^{p|s} - c)$?

$E^+ < (w^{p|s} - c)$

$E^+ > (w^{p|s} - c)$
or $E^- < (w^{p|s} - c)$

$E^- > (w^{p|s} - c)$

Accept projects with probable positive net benefits

Reject projects with probable negative net benefits

Inconclusive: more information required (next valuation method)

Rank projects using a benefit-cost criterion?

Note: total policy costs are expressed as a positive number (c>0). In this Figure $w^{p|s}$ is the individual benefit estimate using any one or a combination of the methods in the non-market valuation "toolkit".

Figure 3. Detailed decision-tree for value transfer (Source: Barton 1999)

BCA: benefit-cost analysis, CEA: cost-effectiveness analysis, NRDA: natural resource damage assessment, AF/RF:available/required funds, AI/RI: available/required information, AT/RT: available/required time;
$w^{p|s}$: value estimate using policy site characteristics conditional study site parameters.

Requirements

Requirements		Comments
Data collection requierement	X **Data is available** X **Need to collect some new data** (e.g. participatory valuation) ☐ Need to collect lots of new data (e.g. valuation based on surveys)	Unit value transfer Value function transfer
Type of data required	X **Quantitative** ☐ Qualitative	Monetary
Expertise and production of knowledge needed	X **Working with researchers within your own field** ☐ Working with researchers from other fields ☐ Working of non-academic stakeholders	"Quick, cheap and dirty" approach with minimal requirement for cross-disciplinary. GIS for policy site characteristics if value function transfer
Software requirements	X **Freely available** ☐ License required ☐ Advanced software knowledge required	Spreadsheet
Time requirements	X **Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	Weeks
Economic resources	X **Low-demanding (less than 6 PMs)** ☐ Medium-demanding (6-12 PMs) ☐ High-demanding (more than 12 PMs)	Weeks
Other requirements		

Where do I go for more information?

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Factsheet prepared by David N. Barton

Shadow pricing

Introduction

When society sets environmental targets on provision of non-marketed ecosystem services it is an implicit valuation of the services. As an example, when a country complies with e.g. the Water Framework Directive it accepts any costs incurred to reach specific water quality levels. Using this approach assumes that it is a socially optimal and well-informed decision to produce a mix of services where water quality regulation is provided at a specific level. If society increases the relative valuation of water quality regulation, the optimal mix of provision of fresh water quality and other services including agricultural products is assumed to be updated through the agreement of new targets. The shadow price is the marginal cost of obtaining an additional unit of the ecosystem service by implementing the environmental target. As an additional unit of the targeted ecosystem service restricts production of other marketed ecosystem services, the change in the mix reflects the relative values. The shadow price society 'pays' for provision of the ecosystem services is the loss from not obtaining the value from producing marketed goods. The method takes into account that economic actors can adjust the way in which the mix of services is produced. Taking this into account avoids exaggeration of the costs and in turn the value of the ecosystem services.

Keywords

Opportunity costs; Implicit valuation; Targets for environmental quality.

Why would I chose this approach?

The methodology is particularly useful in an ecosystem service context to illustrate the scope of ecosystem-based approaches to meet environmental quality targets in contrast to technology-based approaches. The value of ecosystem services to provide e.g. clean water and reduced climate change can be quantified using a shadow pricing approach and compared to the costs it would take to provide these services using technology-based approaches or to the costs of policy inaction. Estimating shadow prices requires identifying the most cost-effective ways of achieving the environmental target. If compared with alternatives, shadow prices can raise awareness of the economic rationale for using ecosystem-based approaches to reach environmental targets.

The spatial scale at which shadow pricing works best is the scale at which environmental targets are set. Most studies therefore choose a regional or national scale. The shadow pricing method measures the costs of providing services that can be delivered from changes in ecosystems; specifically the costs of changes in land, freshwater and marine management. The main criticism of using this methodology is that it is not based on preference assessment. The assumption that the environmental targets reflects preferences in society at large, can be a strong assumption and needs to be acknowledged when the method is used. An advantage of using this methodology is that its application generates knowledge about trade-offs and synergies between provisions of different ecosystem services. The approach is well-known by economists, but only a few examples exist in ecosystem services research.

What are the main advantages of the approach?

- It is a recognised principle in economics, it draws on modelling relationships between provision of different outcomes using existing data;
- Avoids hypothetical biases related to stated preference methods;
- Well suited to conducting sensitivity analysis as a way of analysing the implications of uncertainty;
- Can be used to provide public policy rationales for providing ecosystem services and can be linked directly to land use policies.

What are the constraints/limitations of the approach?

- Requires the compilation of large data sets;
- Needs extensive modelling competence;
- The method relies on the estimates of the cost and effectiveness of different management measures.

What types of value can the approach help me understand?

Shadow pricing is highly appropriate to elicit monetary values and anthropocentric instrumental values of nature's benefits, including both direct use and indirect use values. It is not suitable for evaluating the intrinsic value of nature, neither is it applicable to elicit option, bequest and existence values.

How does the approach address uncertainty?

The valuation approach is well-suited for sensitivity analysis. By systematically varying key model parameters the shadow pricing approach can reveal how the valuation depends on critical natural science and socio-economic assumptions.

How do I apply the approach?

The flowchart below (figure 1) provides a short description of the steps in the application of shadow pricing. The steps can roughly be divided in two parts. The first analytical part (steps 1-3) organises the data, conducts the statistical analysis and estimates a production frontier model. The second application part (steps 4-5) will vary depending on the decision context. In the flowchart below the steps relate to using the method for evaluating the consequences of alternative policies.

Figure 1. Steps involved in the application of Shadow pricing

Requirements

Requirements		Comments
Data collection requirement	**X Data is available** ☐ Need to collect some new data (e.g. participatory valuation) ☐ Need to collect lots of new data (e.g. valuation based on surveys)	
Type of data required	**X Quantitative** ☐ Qualitative	
Expertise and production of knowledge needed	☐ Working with researchers within your own field **X Working with researchers from other fields** ☐ Working with non-academic stakeholders	
Software requirements	☐ Freely available **X License required** **X Advanced software knowledge required**	For example GAUSS requires a licence and specialist knowledge to derive cost-effective alternatives and implicitly the price.
Time requirements	**X Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	**X Low-demanding (less than 6 PMs)** ☐ Medium-demanding (6-12 PMs) ☐ High-demanding (more than 12 PMs)	
Other requirements		

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Factsheet prepared by Mette Termansen & David N. Barton

METHOD FACTSHEET

Production function approach

Introduction

The production function approach (PFA) can be used in situations where a marketed good or service is produced with both man-made and ecosystem inputs. For example, many agricultural crops are dependent on insect pollination and the value of increased pollination can be estimated from the increased revenues from higher yields or improved crop quality associated with higher level of pollination by insects. The PFA is therefore a method designed to value indirect use values. The challenges involved in its application are that data on the relationships between the services (regulation and provision services) and on other non-environmental inputs are often difficult to obtain. The method is therefore not often used, despite its great potential for illustrating the value of taking an ecosystem services approach. However, it has been used to value e.g. water quality improvements resulting in reduced costs of water purification, increased agricultural productivity due to better pollination and increasing soil carbon stocks. A caveat related to the use of this methodology is that the researcher needs to account for inputs other than those from ecosystems. The production of marketed products requires both man-made input as labour and machinery, as well as land and ecosystem based processes. Not accounting for this can lead to the criticism that the valuation is exaggerating ecosystem service values.

Keywords

Production functions; Indirect use values; Valuation of ecological processes

Why would I chose this approach?

The methodology is particularly useful in an ecosystem service context to illustrate the invisible value of ecosystem processes. The value of insect pollination securing provision of some agricultural crops is a well-known example. It relies on the functional relationship between ecosystem service, man-made input factors and the production of marketed products. With this information the methodology can be used to raise awareness of the economic rationale for investing in healthy ecosystems to support the production of marketed products.

The spatial scale at which PFA works best is often relatively fine scale e.g. the field scale in relation to agricultural products. Most studies therefore rely on plot data to estimate the functional relationships. Such plot data can be based on long-term field trials or intensive sampling in agricultural fields across many plots. Obtaining this kind of data is therefore the main obstacle to the use of this methodology. In terms of the valuation, the approach is simple as it relies on prices in the market which are directly observable. The approach has been used for awareness raising of the general public, with farmers to help them include this aspect into their farm management, and as a rationale for developing subsidy schemes to improve the sustainability of farming practises.

What are the main advantages of the approach?

- Recognised and established approach;
- Draws on scientific data on the relationships between ecosystem properties and production of marketed goods;
- When the underlying data is rich, uncertainties in the linkages can be addressed;
- The method can provide public policy rationales for providing ecosystem services and can be linked directly to land management initiatives and policies.

What are the constraints/limitations of the approach?

- Requires collection of large field data sets (cross-sections or time-series) on environmental conditions and inputs to production which can be a constraint for the application to individual case studies;
- Requires modelling competences, which can also be prohibitive.

What types of value can the approach help me understand?

The production function approach is highly appropriate to capture ecological and monetary values, as well as anthropocentric instrumental values, including both direct and indirect use values. It is not appropriate to elicit sociocultural values and intrinsic values of nature. It also has serious limits when used to grasp bequest and existence values.

How does the approach address uncertainty?

The production function methods address uncertainty in a very direct way, as it enables analysis of the value implications of the uncertainty about the relationship between ecological processes. Functional relationships between ecosystem processes are most often highly uncertain and the production function approach allows an explicit analysis of how the range of the strengths in the ecological relationships translates into economic value ranges.

How do I apply the approach?

The flowchart below (Figure 1) gives a short description of the steps involved in applying the production function approach. The steps can roughly be divided in two parts. The first analytical part (steps 1-3) organises the data, conducts the statistical analysis and estimates a production frontier model. The second application part (steps 4-5) will vary depending on the decision context. In the flowchart below the steps relate to using the method for evaluating the consequences of alternative policies e.g. giving subsidies to farmers to plant flower strips to support pollination or schemes to promote management activities to increase carbon stocks in soils, partially to increase long-term productivity of soils.
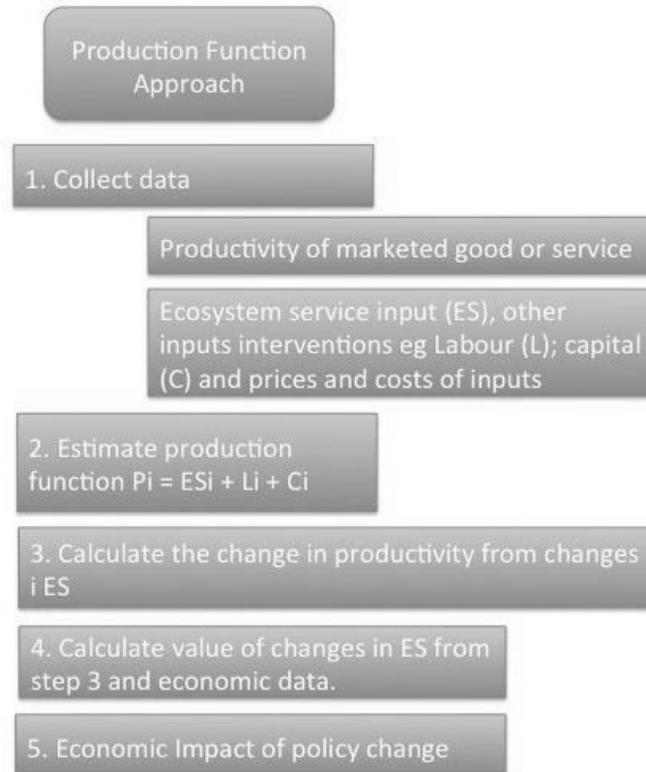
Figure 1. Steps involved in applying the production function approach.

Requirements

Requirements		Comments
Data collection requirement	□ Data is available □ Need to collect some new data (e.g. participatory valuation) **X Need to collect lots of new data (e.g. valuation based on surveys)**	
Type of data required	**X Quantitative** □ Qualitative	Time series for single plots and/or plots of a representative sample of variation in land-use conditions
Expertise and production of knowledge needed	□ Working with researchers within your own field **X Working with researchers from other fields** □ Working of non-academic stakeholders	Experts in the production technology in question (e.g. agronomists, hydrologists, ecologists)
Software requirements	**X Freely available** □ License required □ Advanced software knowledge required	Any statistics package
Time requirements	□ Short-term (less than 1 year) □ Medium-term (1-2 years) **X Long-term (more than 2 years)**	If the data is not available from a previous study
Economic resources	□ Low-demanding (less than 6 PMs) **X Medium-demanding (6-12 PMs)** □ High-demanding (more than 12 PMs)	For the analysis assuming the data have been collected
Other requirements		

Where do I go for more information?

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Factsheet prepared by Mette Termansen & David N. Barton

Mitigation cost-based valuation

Introduction

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 avoiding, mitigating or restoring the loss of services ecosystems provide. As costs are estimated based on observable market-prices it is a group of methods that is also accepted in guidelines on experimental ecosystem accounting (EEA) within the system for economic and environmental accounting (SEEA)(UN 2014). Cost-based methods give a conservative estimate of the value of ecosystem services provided that the most cost-effective actions for avoiding, mitigating, restoring, compensating and offsetting environmental damages have been undertaken. Actions may be specifically designed to address a particular ecosystem service, but costs are often representative of bundles of ecosystem services. Mitigation cost-based valuation methods are associated with steps of the "mitigation hierarchy" (BBOP 2009a) (Figure 1).
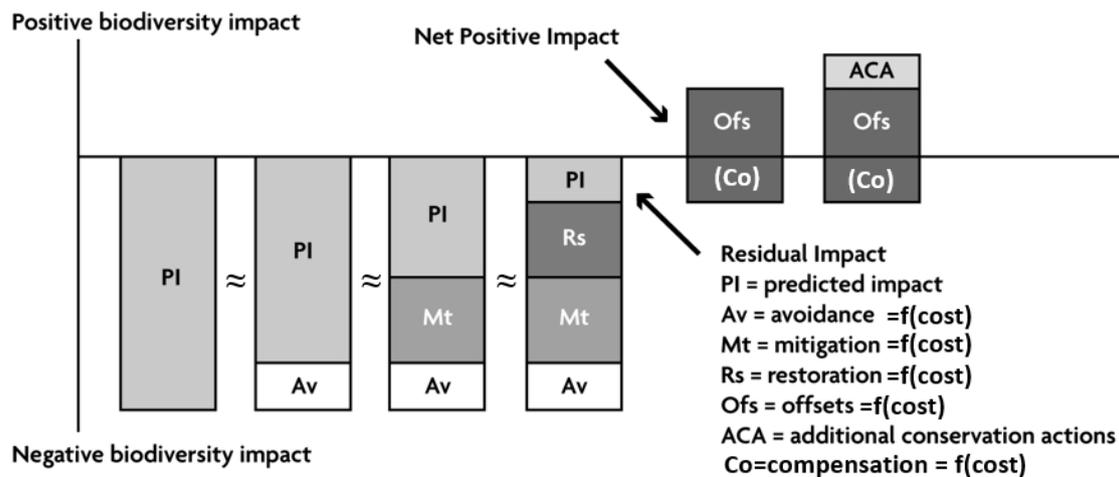

Figure 1. The mitigation hierarchy. Source: adapted from BBOP (2009a)

While the aim of avoidance, mitigation, restoration, compensation or offsetting actions is 'no net loss' to ecosystem services, the sum of action costs is not necessarily equal to the economic impacts if no actions had been undertaken. In other words, the costs of actions do not necessarily equal the welfare effects of impacts. The assumption is that if actions have been undertaken their costs are less than the expected damages to ecosystem services. In practice, actual avoidance, mitigation, restoration, compensation costs incurred may be inflated by ineffective actions. The cost of actions depends on the regulatory standards for environmental liability in the particular jurisdiction of the project (Vatn et al. 2014). Monetary compensation (Co) for damages may in some jurisdictions be required because of negligence (no averting, mitigating or restoration actions have been undertaken).

Keywords

Avoidance costs; Mitigating costs; Restoration costs; Offset costs; Compensation costs.

Why would I chose this approach?

Cost-based methods are accepted for SEEA purposes. They are seen as more reliable than other approaches because they are based on observed market-prices. Ideally, costs are 'operational' in that they are the result of observed actions as part of environmental planning, impact assessment and management. The valuation objective is to determine the sum of costs imposed by environmental regulatory standards, under the assumption that they are a proxy for social value of the ecosystem services protected by the standards. Broadly speaking, cost-based methods are often proxies for multiple ecosystem services - averting and restoring actions target ecosystem condition, rather than specific services. Some mitigation actions and compensation costs may be aimed at particular ecosystem services.

Cost-based methods are landscape and project specific, local scale and high-resolution. They are recommended for SEEA purposes and have been applied across a number of decision contexts – awareness-raising, priority-setting in benefit-cost analysis of project alternatives and the design of biodiversity offsets as well as providing the basis for economic liability.

What are the main advantages of the approach?

Methodological
- Ease of use;
- Speed of use;
- Draws on existing data;
- Covers wide range of ES.

Governance
- Regulatory compatibility;
- Recognised and established accounting approach.

What are the constraints/limitations of the approach?

Methodological constraints
- Does not include welfare measures;
- Uncertain effectiveness of mitigation, restoration and offsetting actions are not possible to quantify ex ante (see appendix). The less effective a measure the more valuable the ecosystem services appear;
- When applied without basis in actual projects, ad hoc assumptions regarding environmental liability standards and potentially feasible actions are required (generating hypothetical costs). When exploring cost-effectiveness of actions the method has commonalities with 'shadow pricing';
- Environmental modelling may be required to assess effectiveness of averting, mitigating and restoring actions on ecosystem service provision (modelling costs).

Governance constraints
- May not reflect environmental liability legislation;

What types of value can the approach help me understand?

Mitigation cost-based methods are highly appropriate to value ecological values and intrinsic values of nature, as well as to elicit option values. They are less suitable to unfold socio-cultural values and relational values, and not appropriate to capture existence value.

How does the approach address uncertainty?

When aiming to apply cost-based methods, it is important to take into account that these methods are conservative and uncertain proxies for the value of avoiding variable future ecosystem service losses.
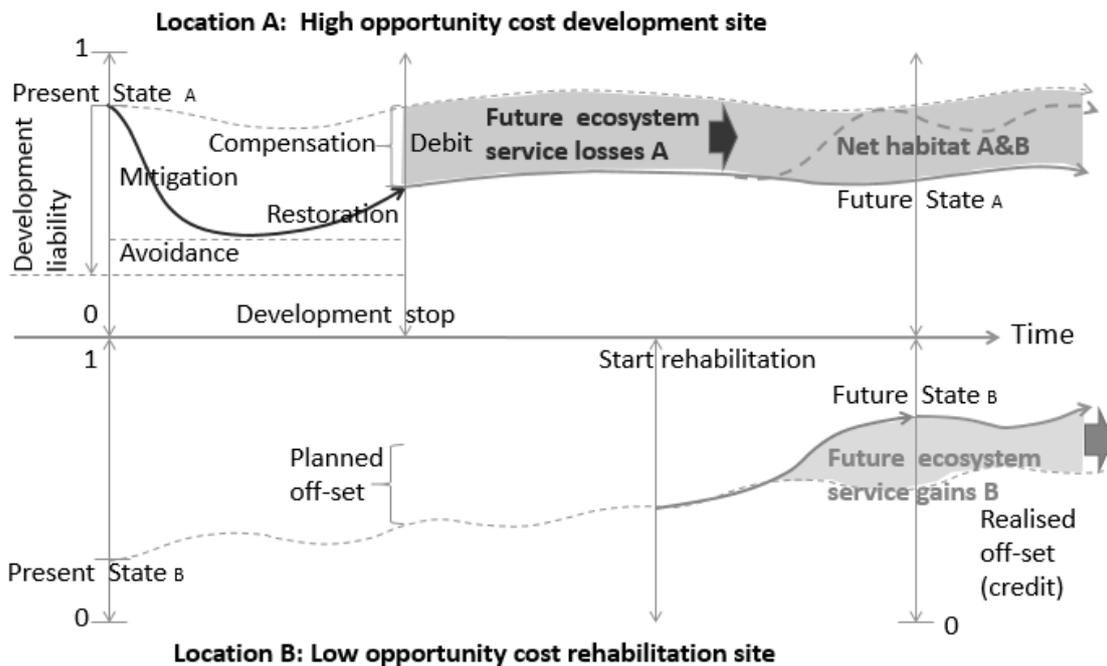

Figure 2. Uncertainty in the application of mitigation cost based methods. Source: adapted from Barton et al. (2011)

As demonstrated in the figure above (Figure 2), avoiding, mitigation and restoration actions are substitutes for one another and should be subject to cost-effectiveness analysis. As a rule of thumb in the mitigation hierarchy, avoidance is preferred to mitigation, which is preferred to restoration and offsetting – following the principle that early precautionary measures are preferable to ex-post reparation. In some regulatory contexts monetary compensation for environmental liability may be required in cases of wilful negligence (lack of avoidance). Off-site offsetting provides the potential for a more cost-effective approach to no net loss of ecosystem services. The equivalence and cost-effectiveness of offset measures over time is more uncertain than on site measures. In summary, the more cost-effective the design of actions, the lower the inferred value of ecosystem services.

How do I apply the approach?

Figure 3. A stepwise approach to the application of mitigation-cost based methods.

Requirements

Requirements		Comments
Data collection requierement	X **Data is available** ☐ Need to collect some new data (e.g. participatory valuation) ☐ Need to collect lots of new data (e.g. valuation based on surveys)	If based on actual or potentially feasible measures
Type of data required	X **Quantitative** ☐ Qualitative	
Expertise and production of knowledge needed	X **Working with researchers within your own field** ☐ Working with researchers from other fields ☐ Working of non-academic stakeholders	Working with project managers
Software requirements	X **Freely available** ☐ License required ☐ Advanced software knowledge required	Spreadsheet
Time requirements	X **Short-term (less than 1 year)** ☐ Medium-term (1-2 years) ☐ Long-term (more than 2 years)	
Economic resources	X **Low-demanding (less than 6 PMs)** ☐ Medium-demanding (6-12 PMs) ☐ High-demanding (more than 12 PMs)	
Other requirements		

Where do I go for more information?

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Factsheet prepared by David N. Barton

Travel cost valuation

Introduction

The travel cost methods (TCM) is based on the observation that recreational services can only be realised through physical access to nature. This implies that individuals seeking to enjoy the service will need to spend resources (time and money) to travel to the site. The travel activity is a reflection of the use value this service has to people. The travel costs method was first applied in the US in 1959 to value the recreational use of nature. There are basically two different types of travel cost methods; one based on a valuation of a single site and one based on choices between multiple sites. In this overview the use and requirements for these two methods are described separately. The single site method is simple and is appropriate when the site in question is of particular interest and significance. The multi-site method is appropriate when the researcher is interested in valuing the attributes of recreational sites, i.e. to determine the importance of environmental attributes, recreational facilities and accessibility, not simply site access. Accessibility to the sites must be calculated using GIS (and preferably distances to the sites through the road network) to generate accurate value estimates. Econometric methods are used to estimate recreational demand functions (single sites) and models of choice of visit (multiple sites).

Keywords

Accessibility; Recreational services; Direct use values

Why would I chose this approach?

TCM has been extensively used to demonstrate the value of, e.g. forests, for services other than timber production. This is potentially powerful for awareness raising. In existing studies, TCM has successfully been used to show that provisioning services often only account for a small part of the services associated with natural or semi-natural areas. The recreation value has also been used to make the economic case for afforestation initiatives in a general sense. However, there are few applications of TCM in real decision making in relation to concrete project evaluations.

The spatial scale at which TCM works best depends on the type of recreational activities being valued. The scale needs to include the range of distances people travel to experience nature. If the recreational activity includes trips to unique sites to which recreationists travel great distances, the spatial scale of analysis needs to be larger than if the study focuses on park recreation in an urban context. Most studies choose a regional scale or a national scale. The TCM directly measures recreational services. It can be argued that the TCM provides conservative estimate as the value of natural and semi-natural habitats are also reflected in other markets, such as the house market (see the description of the Hedonistic property pricing method). A challenge when applying the TCM is the costing of time, as the researcher needs to make assumption about how respondents could have used their time if not used for recreational travel. Such assumptions are often difficult to validate in empirical studies. In a similar way, spending time on site also reflects the fact that people find the activity worth-while as they could otherwise have spent their time on competing activities. It is customary to include time in the travel costs by using a share of the hourly wage, reflecting that people usually haven't got completely flexible hours of work. Several studies have analysed the

sensitivity of the assumptions about alternative options for people's time and therefore the costs associated with spending time on recreational travel. The time spend on-site is not considered a cost and not accounted for in travel costs studies.

What are the main advantages of the approach?

- Travel cost is a recognised and established approach;
- It draws on revealed data (which is often stated as an advantage as hypothetical biases from using stated preference methods are avoided);
- The method can be used to provide a public policy rationale for providing green spaces for recreational activities;
- It can be used to study designs of recreational site quality.

What are the constraints/limitations of the approach?

- It requires large data sets on recreational activities;
- It requires extensive GIS pre-processing of travel cost data and site characteristics (multiple site approach);
- The method is specific to the estimation of recreational services and cannot be generalised to estimate a range of other services;
- Results are highly sensitive to assumptions about cost of time.

What types of value can the approach help me understand?

Travel cost methods are highly appropriate to elicit sociocultural values and anthropocentric instrumental values attached to nature's benefits, including direct use values. It is not appropriate for measuring ecological values, or any kind of intrinsic values of nature. Neither is it applicable to elicit indirect use, option, bequest or existence values.

How does the approach address uncertainty?

The method is well-suited for sensitivity analysis to uncover the importance of behavioural assumptions underlying the economic estimates. It is important to bear in mind that this method captures the values of visitors well, but is not as suitable for capturing the values of local residence.

How do I apply the approach?

The flowcharts below (Figures 1 & 2) give a short description of the steps to apply TCM using a single site and a multiple site approach. The steps can roughly be divided in two parts. The first analytical part (steps 1-3) organises the data, conducts the statistical analysis and estimates a model of recreational behaviour. This is often as far as many research papers take the analysis. The second application part (steps 4-5) will vary depending on the decision context. In the flowcharts below the steps relate to using the method for finding aggregate values of different policy changes for awareness-raising purposes or concrete policy evaluation.
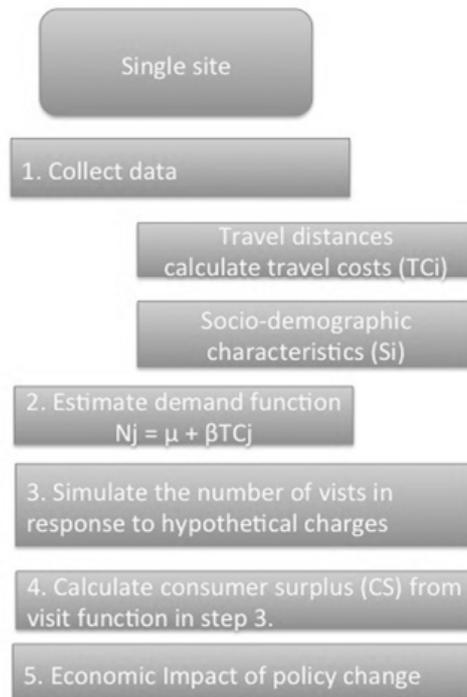
Figure 1. Steps in a zonal travel cost analysis (single site); i refers to individual; j refers to geographical zone.
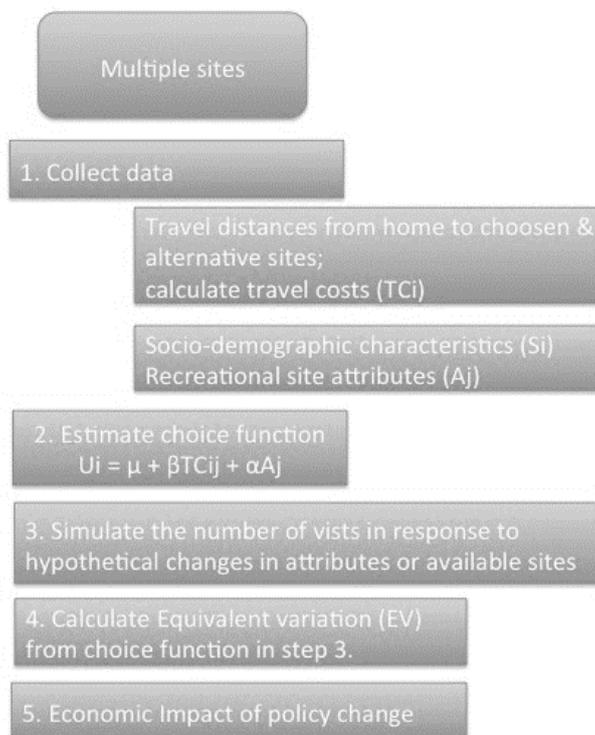

Figure 2. Steps in a discrete choice travel costs analysis (multi-sites).

Requirements

Requirements		Comments
Data collection requirement	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) **X Need to collect lots of new data** (e.g. valuation based on surveys)	
Type of data required	**X Quantitative** ☐ Qualitative	
Expertise and production of knowledge needed	☐ **Working with researchers within your own field** ☐ Working with researchers from other fields ☐ Working of non-academic stakeholders	Data on travel costs are mainly collected by economists themselves. GIS estimates of network distances and data on site attributes are sometimes collected with help from researchers from other fields.
Software requirements	**X Freely available** **X** License required ☐ Advanced software knowledge required	For example "R" ArcGIS requires a licence Multiple-site travel costs estimates are usually conducted in specialised software such as STATA, NLogit or similar, but free software exist such as Blogene.
Time requirements	☐ Short-term (less than 1 year) **X Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	
Economic resources	☐ Low-demanding (less than 6 PMs) **X Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	
Other requirements	-	

Where do I go for more information?

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Factsheet prepared by Mette Termansen & David N. Barton

Hedonic property pricing

Introduction

Hedonic pricing is the study of multi-correlation between environmental characteristics of a good and its sales price. The Hedonic property pricing (HPP) method can be used to estimate monetary values for ecosystem services that directly affect 'amenities' of properties which in turn are reflected in property prices. The HPP method requires large data sets of property sales statistics with physical characteristics of the property itself - and particularly for ecosystem services - e.g. characteristics of green infrastructure in the neighbourhood. Proximity and accessibility to green structures must be calculated using GIS. GIS data of high resolution is needed if the analysis is also to capture quality of green infrastructure, which is key to linking the analysis to ecosystem services. Econometric methods are used to control for differences in property and neighbourhood characteristics. In particular, spatial regression techniques are used to control for spatial auto-correlation between neighbourhood characteristics related to green infrastructure, and other non-environmental characteristics.

Keywords

Property prices: Amenities: Spatial analysis: Awareness raising.

Why would I chose this approach?

HPP is potentially powerful for *awareness raising* purposes because it can demonstrate to individual property owners the increase in private market values of public goods from green infrastructure amenities (whether public or private property). While marginal values for a specific green space on a given property may be small, aggregating values across all properties in the neighbourhood of a green space can show large total values, which may compete with real estate values of developing the green space.   However, there are few applications of HPP to actual land-use & zoning decisions. Perhaps this is due to few studies using GIS data that controls for site qualities, and problems in finding robust econometric hedonic price functions because of spatial auto-correlation.

The spatial scale at which HHP works best is for whole urban areas with a high spatial density of property sales and large variability in availability of green infrastructure across neighbourhoods. The HPP method cannot distinguish directly between ecosystem services, but rather between the relative importance's of different green infrastructures. The link from a property's green structures to ecosystem functions has to be inferred using other data (e.g. green spaces may mitigate property flood risk as well as provide recreation). Such ecosystem functional inferences are easier if it the spatial resolution of the analysis is good enough to include qualities of green infrastructure, other than proximity affect prices.   However, neighbourhood amenities that are directly perceivable to house buyers are those likely to affect prices, typically related to cultural ecosystem services.

What are the main advantages of the approach?

- Recognised and established approach;
- Potentially compatible with national accounting standards;

- Draws on existing data;
- Covers wide range of ES;
- Uncertainty can be addressed;
- Provides capital values of ES directly for use directly in natural capital accounting;
- Provides both public and private economic rationales for providing ecosystem services /amenities from green infrastructure;
- Can be linked directly to land use zoning proposals.

What are the constraints/limitations of the approach?

- Requires large panel data sets of property sales data;
- Requires extensive GIS pre-processing of neighbourhood characteristics;
- Results are sensitive to modelling assumptions regarding spatial auto-collinearity.

What types of value can the approach help me understand?

Hedonic property pricing is highly appropriate to elicit monetary values, direct use values and anthropocentric instrumental values related to the benefits of nature. They are not suitable to elicit intrinsic values of nature as well as bequest and existence values. They also have limitations to grasp ecological values, indirect use values and option values.

How does the approach address uncertainty?

Hedonic pricing uses multi-variate methods which make it possible to test whether variables explaining property prices are statistically significant. The covariance between green space characteristics and other urban neighbourhood characteristics can be evaluated. Confidence intervals for the marginal contribution of each characteristics of green space to property prices can also easily be calculated.

How do I apply the approach?

The flowchart below provides with a short description of the steps to apply hedonic property pricing. The steps can roughly be divided in two parts. The first analytical part (steps 1-3) organises the data, conducts the spatial statistical analysis and estimates the marginal individual contributions of each property characteristics. This is often as far as many research papers take the analysis. The second application part (steps 4-6) will vary depending on the decision context. In the flowchart below the steps relate to using the method for finding aggregate values for awareness-raising purposes.
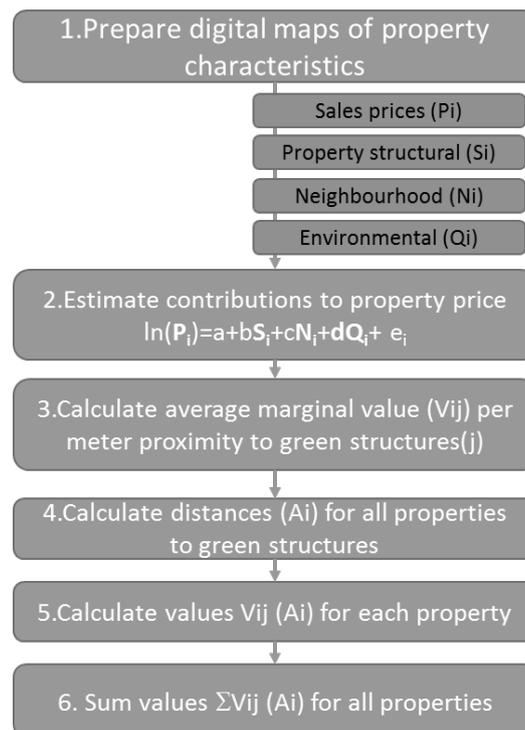
Figure 1. Stepwise approach to the HPP method

Requirements

Requirements		Comments
Data collection requierement	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) ☐ **X Need to collect lots of new data** (e.g. valuation based on surveys)	
Type of data required	**X Quantitative** ☐ Qualitative	
Expertise and production of knowledge needed	☐ Working with researchers within your own field **X Working with researchers from other fields** ☐ Working of non-academic stakeholders	
Software requirements	**X Freely available** ☐ License required ☐ Advanced software knowledge required	For example "R"
Time requirements	☐ Short-term (less than 1 year) **X Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	If property sales data is available
Economic resources	☐ Low-demanding (less than 6 PMs) **X Medium-demanding (6-12 PMs)** ☐ High-demanding (more than 12 PMs)	If property sales data is available
Other requirements	-	

Where do I go for more information?

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Factsheet prepared by David N. Barton and Anders L. Madsen

Stated preference valuation

Introduction

Stated preference valuation is family of techniques which use individual respondents' statements about their preferences to estimate change in utility associated with a proposed increase in quality or quantity of an ecosystem service or bundle of services (Bateman, Carson et al. 2002). Respondents are presented with one or more hypothetical policy or project scenarios that lead to a specified environmental change compared to a baseline situation. The answers respondents give, in the form of monetary amounts, ratings, or other indications of preference, are scaled following an appropriate model of preferences to yield a measure of value of the proposed ecosystem service change. This value is often monetary expressed as people's willingness to pay (WTP). Stated preferences are often elicited through surveys (typically web, phone, mail or in-person) that use questionnaires following strict guidelines. The surveys are administered to representative samples of the people affected by the environmental change and mean WTP per household or person is then aggregated over the relevant population as a measure of welfare change.

The two most common forms of stated preference methods are contingent valuation (CV) and choice experiments (CE) (Hensher, Rose et al. 2005). CV elicits value by directly asking respondents for their WTP for the change in the ecosystem service(s). CE breaks the description of the environmental good into physical attributes, where each attribute has different levels. The respondents then face a number of choice sets with different combinations of physical attribute levels combined with a cost attribute. This design indirectly reveals the respondents' trade-offs between money and changes in individual attributes. This is used to calculate their WTP for a change in ecosystem services as described by the combinations of the attributes.

Keywords

Hypothetical policy scenario; Willingness to pay; Survey; Representative sample; Individual welfare change; Trade-offs.

Why would I chose this approach?

Stated preference (SP) methods are highly flexible. Their flexibility is both an advantage and a potential source of misuse. SP can in principle generate monetary willingness to pay (or accept) estimates of direct, indirect or non-use values. Hypothetical scenarios for measures delivering just about any ecosystem service can be defined. SP methods can address a number of decision contexts. They have been used to generate aggregate willingness-to-pay estimates for public goods for the purposes of awareness-raising. Their relevance for systems of environmental and economic accounting is limited because of recommendations to use only exchange-based data (UN 2014). Stated preference values are in principle well suited for inclusion in benefit-cost analysis and decision-support for priority-setting, although their application to actual policy choices outside the academic literature has been limited (Laurans, Rankovic et al. 2013).

SP methods are in principle well-suited for instrument design, such as assessing willingness-to-pay for user-financed public utilities, which may be co-produced by ecosystem functions (e.g. water and sewage) (Brouwer, Barton et al. 2009). Where the regulatory system permits it, stated preference methods may be used 'as a valuation method of last resort' to assess the equivalence of restoration measures in natural resource damages (Gard and Desvouges 2013). SP is particularly flexible in terms of defining hypothetical institutional contexts for delivery of ecosystem services. SP is a 'value articulating institution' (Vatn 2005) because values are highly contingent on the institutional framing used in the survey. SP methods require statistically representative samples of populations concerned with public policies. For this reason, they often sample respondents at city-wide, regional or national level spatial scale. Spatial resolution of the SP data can also be high if individual respondents are asked to react to hypothetical changes in ecosystem services in their local environment.

What are the main advantages of the approach?

Methodological
- Recognised and established approach within environmental economics;
- Covers wide range of ES, use and non-use values;
- Trade-offs between ES and a few other context characteristics can be evaluated using choice experiments;
- Uncertainty at the population level can be addressed, as quantified variance in willingness-to-pay across respondents;
- Representative sampling of populations.

Governance
- Highly flexible in terms of defining management and policy scenarios;
- Can be combined with consultative focus group methodologies;
- Structured opinion polling, referendum-type data.

What are the constraints/limitations of the approach?

Because of the wide variety of contexts to which SP has been applied, not all problems apply to all SP studies at once. However, looking across SP studies the main challenges can be summarised as (Vatn 2005):

- Information problems
  - Demarcation and composition of ecosystem services; valuation scenarios specify management actions for land or water use which affect multiple ecosystem services;
  - Functional invisibility of ecosystem services; difficulties in communicating multiple ecosystem functions in valuation scenarios;
  - Incommensurable or lexicographic preferences; respondents may be unwilling to accept trade-offs between ecosystem services and money.
- Individual values, ethics, social choice
  - Willingness-to-pay measures assume respondents don't hold rights to the status quo in terms of environmental quality;
  - Respondents may hold norms and moral commitment to their environment that they are not willing to trade against prices in monetary exchange.
- Rational choice assumptions and biases

- o Part-whole bias; the sum of WTP of parts of ecosystems typically exceeds willingness to pay for the system as a whole;
- o Sequence bias; the order in which parts of ecosystems are valued affects willingness-to-pay; the framing of choices affects values ;
- o Yeah-saying; stated preference surveys often overestimate willingness-to-pay relative to what respondents would actually pay in revealed preference situations;
- o Prices informing preferences; respondents will not have pre-formed monetary preferences for ecosystem services; even for market goods price often assists consumers in forming preferences;
- o Socially contingent preferences; respondents preferences change with the social setting and their roles in those settings (as consumers, voters etc.).

What types of value can the approach help me understand?

Stated preference methods are highly appropriate to elicit monetary values. Taking into account the Total Economic Value framework, SP methods are capable of capturing direct use values, option values, bequest values and existence values. They are limited in their ability to provide ecological values and values for the intrinsic value of nature.

How does the approach address uncertainty?

The methods aim at obtaining a representative sample of the population potentially affected by the policy or project. The method generates a probability distribution of 'willingness-to-pay' or '–to-accept' for the population, which can be used to calculate confidence intervals for the stated value of a change in the ecosystem service. Stated preference valuation uses multi-variate methods which make it possible to test whether variables explaining 'willingness-to-pay' or 'willingness-to-accept' are statistically significant.

How do I apply the approach?

For an overview of the consecutive methodological steps, see Figure 1. Stated preference methods are most time consuming in the initial steps of (1) defining the valuation scenario and (2) designing the survey. Once these steps are complete, testing implementation and analysis are relatively straightforward activities. Figure 1 illustrates the dependence of generated values on a large number of inter-related survey design decisions which make SP-values highly context specific. Choice experiment and contingent valuation differ from one another mainly in (2) the design of the choice situation and (7) estimation of willingness-to-pay for ecosystem service.
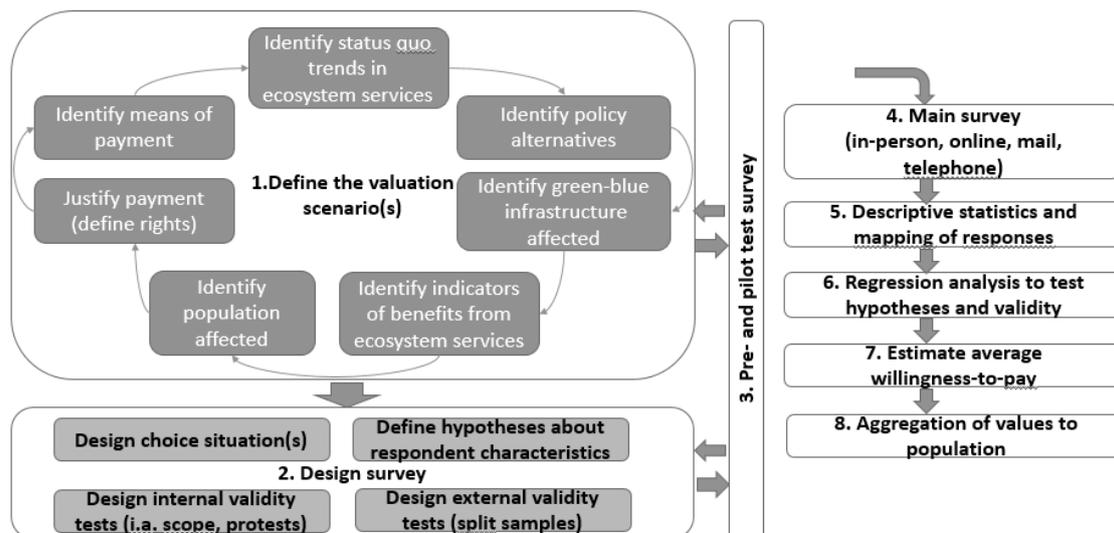
Figure 1. Stepwise approach to stated preference methods.

Requirements

Requirements		Comments
Data collection requierement	☐ Data is available ☐ Need to collect some new data (e.g. participatory valuation) **X Need to collect lots of new data (e.g. valuation based on surveys)**	
Type of data required	**X Quantitative** ☐ Qualitative	
Expertise and production of knowledge needed	**X Working with researchers within your own field** **X Working with researchers from other fields** **X Working of non-academic stakeholders**	SP scenarios often defined through focus groups with stakeholders; high quality studies define environmental characteristics of scenarios with natural scientists
Software requirements	☐ Freely available **X License required** **X Advanced software knowledge required**	Licenced econometric software packages (e.g.STATA, NLOGIT, Sawtooth)
Time requirements	☐ Short-term (less than 1 year) **X Medium-term (1-2 years)** ☐ Long-term (more than 2 years)	
Economic resources	☐ Low-demanding (less than 6 PMs) **X Medium-demanding (6-12 PMs)** **X High-demanding (more than 12 PMs)**	Depending on complexity of the ecosystem service, the scale of the study, and available expertise
Other requirements		

Where do I go for more information?

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