Dunford, R., Harrison, P., Smith, A., Dick, J., Barton, D.N., Martin-Lopez, B., Kelemen, E., Jacobs, S., Saarikoski, H., Turkelboom, F., Verheyden, W., **Hauck, J.**, Antunes, P., Aszalós, R., Badea, O., Baró, F., Berry, P., Carvalho, L., Conte, G., Czúcz, B., Garcia Blanco, G., Howard, D., Giuca, R., Gomez-Baggethun, E., Grizetti, B., Izakovicova, Z., Kopperoinen, L., Langemeyer, J., Luque, S., Lapola, D.M., Martinez-Pastur, G., Mukhopadhyay, R., Roy, S.B., Niemelä, J., Norton, L., Ochieng, J., Odee, D., Palomo, I., Pinho, P., **Priess, J.**, Rusch, G., Saarela, S.-R., Santos, R., van der Wal, J.T., Vadineanu, A., Vári, A., Woods, H., Yli-Pelkonen, V. (2018):
Integrating methods for ecosystem service assessment: Experiences from real world situations
Ecosyst. Serv. **29** (Part C), 499 - 514

http://dx.doi.org/10.1016/j.ecoser.2017.10.014

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

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Abstract

The Ecosystem Services (ES) concept highlights the varied contributions the environment provides to humans and there are a wide range of methods/tools available to assess ES. However, in real-world decision contexts a single tool is rarely sufficient and methods must be combined to meet practitioner needs. Here, results from the OpenNESS project are presented to illustrate the methods selected to meet the needs of 24 real-world case studies and better understand why and how methods are combined to meet practical needs. Results showed that within the cases methods were combined to: i) address a range of ES; ii) assess both supply and demand of ES; iii) assess a range of value types; iv) reach different stakeholder groups v) cover weaknesses in other methods used and vi) to meet specific decision context needs. Methods were linked in a variety of ways: i) as input-output chains of methods; ii) through learning; iii) through method development and iv) through comparison/triangulation of results. The paper synthesises these case study-based experiences to provide insight to others working in practical contexts as to where, and in what contexts, different methods can be combined and how this can add value to case study analyses.

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 (Harrison et al., 2017; Bagstad et al., 2013). Individual ecosystem service tools, however, are often insufficient to meet the varied needs of land management challenges, and practitioners will therefore need to find the right combinations of tools to meet their needs – and to enable them to assess the broad range of values provided by nature (Jacobs et al., 2017). Whilst there are a number of studies that attempt to provide guidance on which tools to use under which circumstances (e.g. Vatn, 2009; Bagstad et al., 2013; Martinez-Harms et al., 2015; Ruckelshaus et al., 2015; Hirons et al., 2016; Grêt-Regamey et al., 2016), there has to date been no study that takes a bottom-up, example-based look at the range of tools required to address real-world case studies and the practical factors that drive the selection and combination of different methods.

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 24 real-world case studies, predominantly in Europe, but also in India, Kenya, Argentina and Brazil (see Table SM1 and Wijna et al., 2016 for further information). These case studies provide a test bed for assessing the utility of ecosystem service tools in practice, and the way in which different tools can be combined to address real-life problems. Within this paper we address three research questions:

1) What methods were combined within the case studies?
2) What factors drove the use of combinations of methods?
3) How were different methods combined within the case studies, and did this add value?

We aim to provide grounded insights and examples to assist others embarking on ecosystem service assessments where priorities are driven by practical end-user needs.

2 Methodological approach

The OpenNESS case-studies address a range of ecosystem management/planning challenges that were selected by practitioners (Table SM1). In each case study a *research team*, funded by the project, worked alongside a team of local *stakeholders* who are involved with the management of and/or have some interest and/or dependency on the case study's central issue. Case study teams were able to choose one or more tools to meet their needs, with training being provided. This paper is based on the research teams' explanations of the factors that influenced their selection and combination of tools to meet the stakeholders' needs.

The methods available for selection by the case study teams are listed in full in Table SM2. There are many ways to group methods but within this paper we group them into seven classes according to the type of ES values assessed: biophysical, socio-cultural or monetary (Gomez-Baggethun et al., 2015), as shown in Figure 1. The classification also reflects the level of stakeholder participation, the level of biophysical realism reflected within the model (following Lavorel et al., 2017) and which parts of the ES cascade the method focusses on (biophysical structures and functions, ecosystem services or benefit and values to humans; Haines Young and Potschin, 2010). The main classes of model are summarised below.

Biophysical models: these process-based models assess biophysical value using a higher level of biophysical realism than approaches based on land-use proxies. They are based on detailed quantitative understanding of biophysical relationships within the environment and tend to focus on the structure/function part of the ES cascade. It is rare, but possible, to include stakeholder participation within the modelling.

Integrated mapping-modelling approaches: these combine spatial approaches with an element of bio-physical modelling to extrapolate from spatial datasets to ecosystem

services. They are often designed specifically to address ecosystem services and include established methods such as InVEST and ESTIMAP (Zulian et al., 2014).

Land-use scoring approaches: this includes approaches based primarily on mapped data that produce ES outputs by applying some kind of expert-scoring. Referred to here as the "matrix approach" these methods include both the simple matrix (Burkhard et al., 2012) which uses only land-use as a proxy for ecosystem service provision, and more advanced versions such as GreenFRAME (Kopperoinen et al., 2014) which build in more biophysical understanding by using additional datasets.

Participatory mapping: these approaches use mapping to capture both spatial and socio-cultural data directly from stakeholders. The priority is on capturing socio-cultural values, but biophysical value (extent and location of biophysical units) are often captured also. It always involves stakeholders and focuses on both ecosystem services and values. Participatory GIS (PGIS) is a commonly used participatory mapping example.

Socio-cultural methods: a wide range of methods that prioritise socio-cultural values for ecosystem services, including non-monetary alternatives to common monetary approaches (e.g. time use, preference assessment) and deliberative and narrative approaches (such as interviews and focus groups). One approach commonly used within OpenNESS is the "photoseries" methodology which involves the assessment of cultural ecosystem services revealed in photos uploaded on social media (e.g. Flickr; Martínez Pastur et al., 2016; Tenerelli et al, 2016).

Monetary methods: approaches that carry out monetary valuation of ecosystem services through a range of means (such as value transfer, revealed or stated preference). Some of these methods include stakeholder participation and all focus on the value/benefit side of the cascade.

Integrative approaches: these methods are designed to synthesise data and are capable of integrating data that cover a wide range of different types of values. Within this paper this class refers to Bayesian Belief Networks (BBNs) and Multi-Criteria Decision Analysis (MCDA). However, it should be noted that a) these approaches do not have to be used to integrate across value types (e.g. BBNs can be used for purely biophysical data) and b) other methods can also play a role integrating across value types (e.g. deliberative workshops, stakeholder meetings or project reports).

		Values					Cascade		
Overarching method class	Name	Biophysical	Socio-cultural	Monetary	Involves stakeholders	Biophyscical model type	Structure/ Function	Ecosystem Service	Benefit/Value
Biophysical modelling	Land use modelling	●			Rarely	Process	●		
	Biophysical modelling	●			Rarely	Process	●	○	
	Ecological models	●			Rarely	Process	●	○	
	Hydrological models	●			Rarely	Process	●	○	
	Climate envelope modelling	●			Rarely	Niche-based	●	○	
	State and Transition Models (STMs)	●			Sometimes	Phenomenological	●	○	○
Int. mapping-modelling	Integrated mapping-modelling approaches	●			Sometimes	Phenomenological-Process	●	●	●
Land use scoring	Matrix approach based on land use data only	●	○		Often	Proxy	○	●	○
	Matrix approach based on multiple datasets	●	◑		Often	Proxy-Phenomenological	○	●	○
Participatory mapping	Participatory/ deliberative mapping	◑	●		Always	Proxy-Phenomenological	○	●	●
Socio-cultural methods	Photo-series analysis	○	●	○	Rarely	N/A	●	●	●
	Scenario development	○	●	○	Always	N/A	●	●	●
	Non-monetary valuation	○	●	○	Always	N/A	○	○	●
	Deliberative valuation	○	●	○	Always	N/A	○	○	●
	Narrative analysis	○	●	○	Always	N/A	○	○	●
	Photo-elicitation surveys	○	●	○	Always	N/A		○	●
	Preference assessment	○	●	○	Always	N/A		○	●
	Time use	○	●	○	Always	N/A		○	●
Monetary methods	Stated preference		○	●	Always	N/A		○	●
	Revealed preference		○	●	Rarely	N/A		○	●
	Monetary valuation		○	●	Often	N/A		○	●
	Benefit-cost analysis		○	●	Often	N/A		○	●
	Cost-based		○	●	Rarely	N/A		○	●
	Value transfer		○	●	Rarely	N/A		○	●
Integrative approaches	Bayesian Belief Networks (BBN)	◑	◑	◑	Often	Varies	●	●	●
	Multi-Criteria Decision Analysis (MCDA)	◑	●	◑	Often	Varies	○	○	●

Figure 1 Overview of broad classes of methods used within this study. Values/Cascade: ● primary priority ◑ secondary priority ○ lower priority; blank = not addressed. "Involves stakeholders" colours reflect the text. Biophysical model types (following Lavorel et al., 2017) reflect level of biophysical realism from those that use land-use as a simple proxy (🡻), through phenomenological models that include additional understanding of the biological mechanisms (🡺,🡽) through to more advanced methods including niche- and trait-based approaches and process models of the biophysical system (🡹).

Data on tool use was collected through a series of questionnaires and workshops with the 24 case study research teams (Figure 2). Initial surveys (Q1) encouraged research teams 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 (Table SM3). These factors, referred to as "*considerations*" within this paper, 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., (this issue);
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, transferable and produced scientifically robust results;

5) particular **methodological considerations**, such as a method's ability to involve stakeholders, provide spatially explicit outputs or address uncertainty;
6) and factors related to the **stakeholder-driven** nature of the OpenNESS research, such as whether the method selection was driven by the end-users themselves.

A further survey (Q2) was circulated after completion of the case studies, in which the research teams were asked to score the extent to which each of the considerations influenced their decision to use each method (0 = not at all; 1 = to some extent; 2 = definitely). They were also asked to assess, in free text: i) their reasons for combining methods; ii) whether the combination of methods they used met their aims; iii) any problems and challenges resulting from combining methods and iv) their views on the impact of method combination on the scientific robustness of the results (Table SM4).

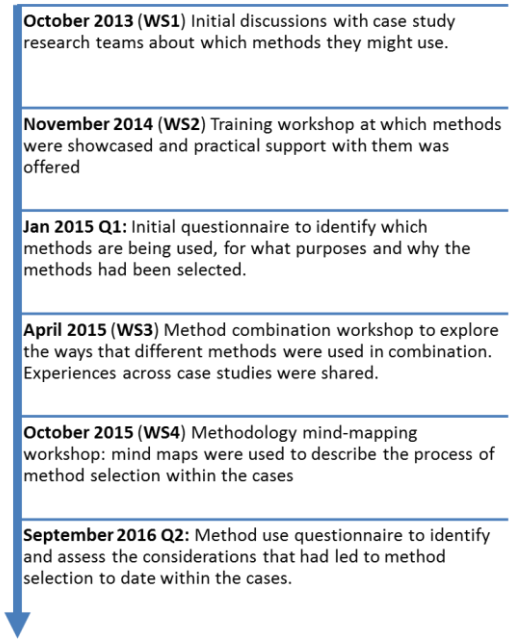


Figure 2 Timeline providing an overview of workshops (WS1-4) and questionnaires (Q1&2) focussed on method combinations.

In addition to survey data, workshops were used to ascertain how the case studies were using methods to meet their specific goals (WS1-4) and to understand how methods were being combined (WS 3-4). The final workshop (WS4) produced participatory mind maps detailing the methods used, the ways in which methods are combined and the considerations that influenced method selection and combination.

The questionnaires and mind maps were thematically analysed across all case studies to identify common factors influencing selection of individual methods and the way in which methods were combined. Where necessary, ad hoc interviews with the case study research teams were used to fill in additional details and clarify uncertainties.

3 Results

3.1 What methods were combined within the OpenNESS case studies?

The 24 case studies cover a wide range of biophysical contexts (e.g. forests, cities, mixed rural areas, rivers and coasts) and varied land management challenges and policy contexts (see SM1 and Dick et al., (this issue), for details). As such, a wide range of methods were selected and combined within the case studies (Figure 3).

The number of methods combined varies widely: most case studies (75%) combined at least four methods and 42% combined six or more, with one (Oslo) combining 15. Socio-cultural and participatory mapping methods were the most commonly used method classes (used in 83% and 67% of studies respectively), with all but two studies using at least one of these methods. Integrated mapping-modelling approaches and biophysical modelling were used less often (46% and 38% respectively) and land-use scoring approaches were only used in 25% of cases, but all but five cases used at least one of these methods. Monetary methods were only used in a third of case studies. Just under half of case studies used either MCDA or BBNs as an integrative method, with two combining both of these methods.

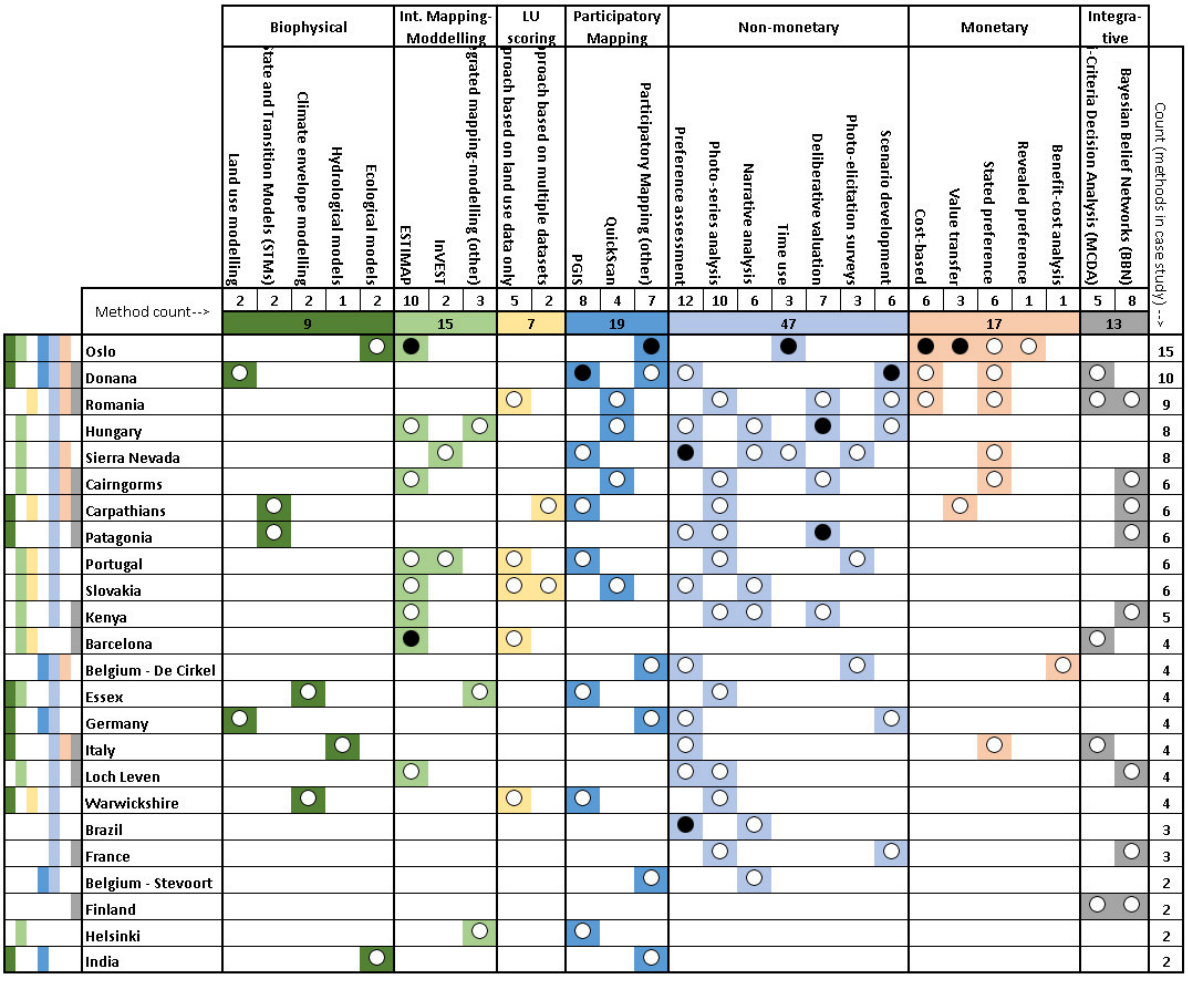


Figure 3: Overview of method usage within the 24 case studies; white circles indicate a single method; black circles indicate more than one method of the same type. Colours reflect overarching method classes; the coloured bars on the left indicate presence or absence of at least one method of each class.

3.2 What factors drive the need for method combination?

Analysis of the questionnaires, mind-maps and supplementary interviews (Table SM4) revealed six overarching factors that drive the need to combine different methods within a case study:

a) a need to assess **a range of different ES** beyond those possible with a single method;
b) 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;
c) a need to assess **different aspects of value** (biophysical, socio-cultural, monetary) within a case study;
d) a need to **engage with different types of stakeholder**;
e) a need to **address methodological concerns** relating to the use of a single method (e.g. to increase robustness, for validation);
f) selecting methods to address **different stages of the research/case study's development**.

The following sections (3.2.1-3.2.6) focus on each of these factors in turn, demonstrating the approaches taken within the OpenNESS case studies with reference to Figures 4 and 5. Figure 4 lists each case study against the capabilities of the models they chose to use (from Figure 1). Figure 5 combines results from all case studies, grouping the method selection considerations according to how they address the six overarching factors for combining methods (a to f above).

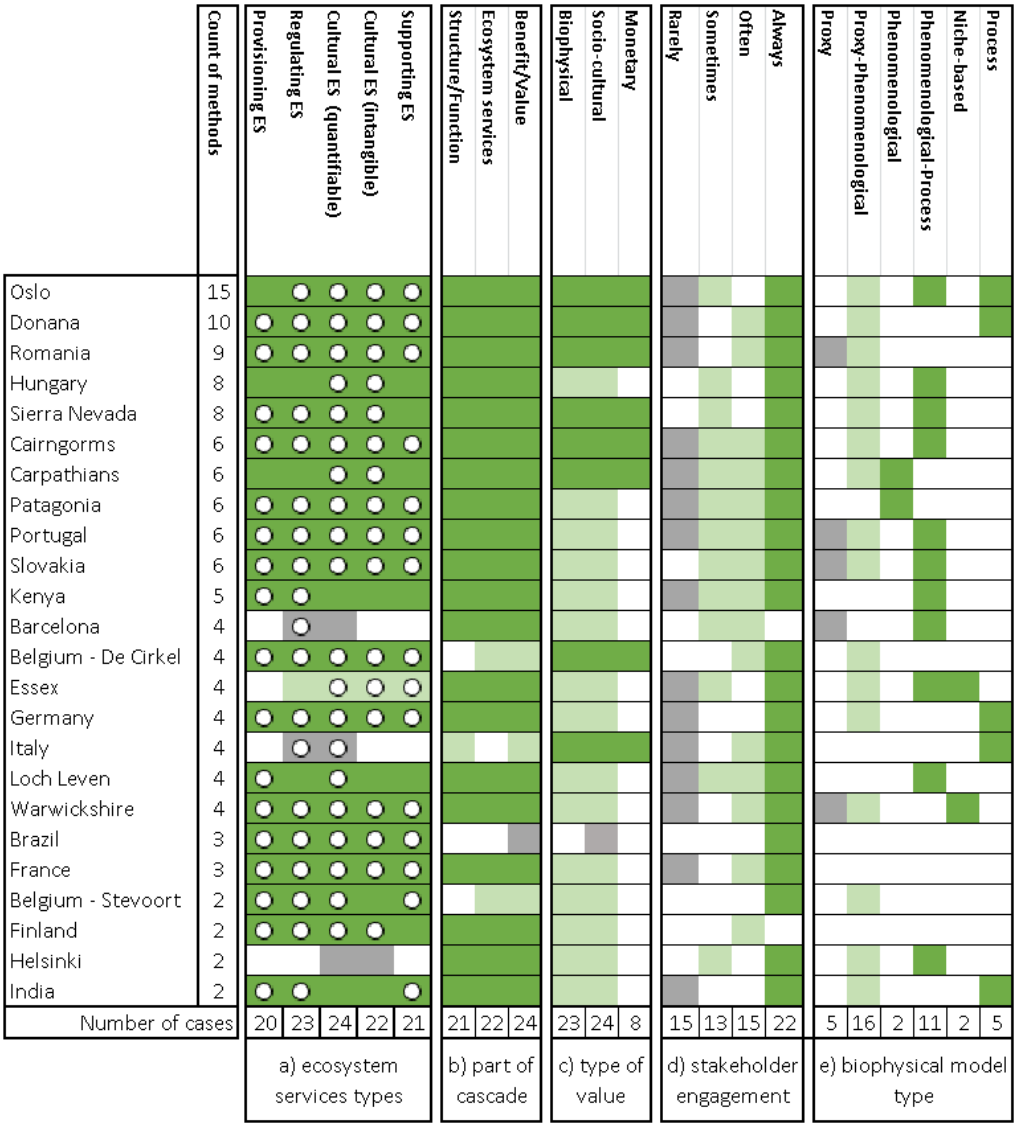


Figure 4. Attributes of methods combined within OpenNESS case studies. Coloured cells indicate at least one method meeting the criteria within the case. Key white dots indicate more than one method addressing that type (ES types only). Shades of green used to illustrate increasing levels of each attribute (a-f).

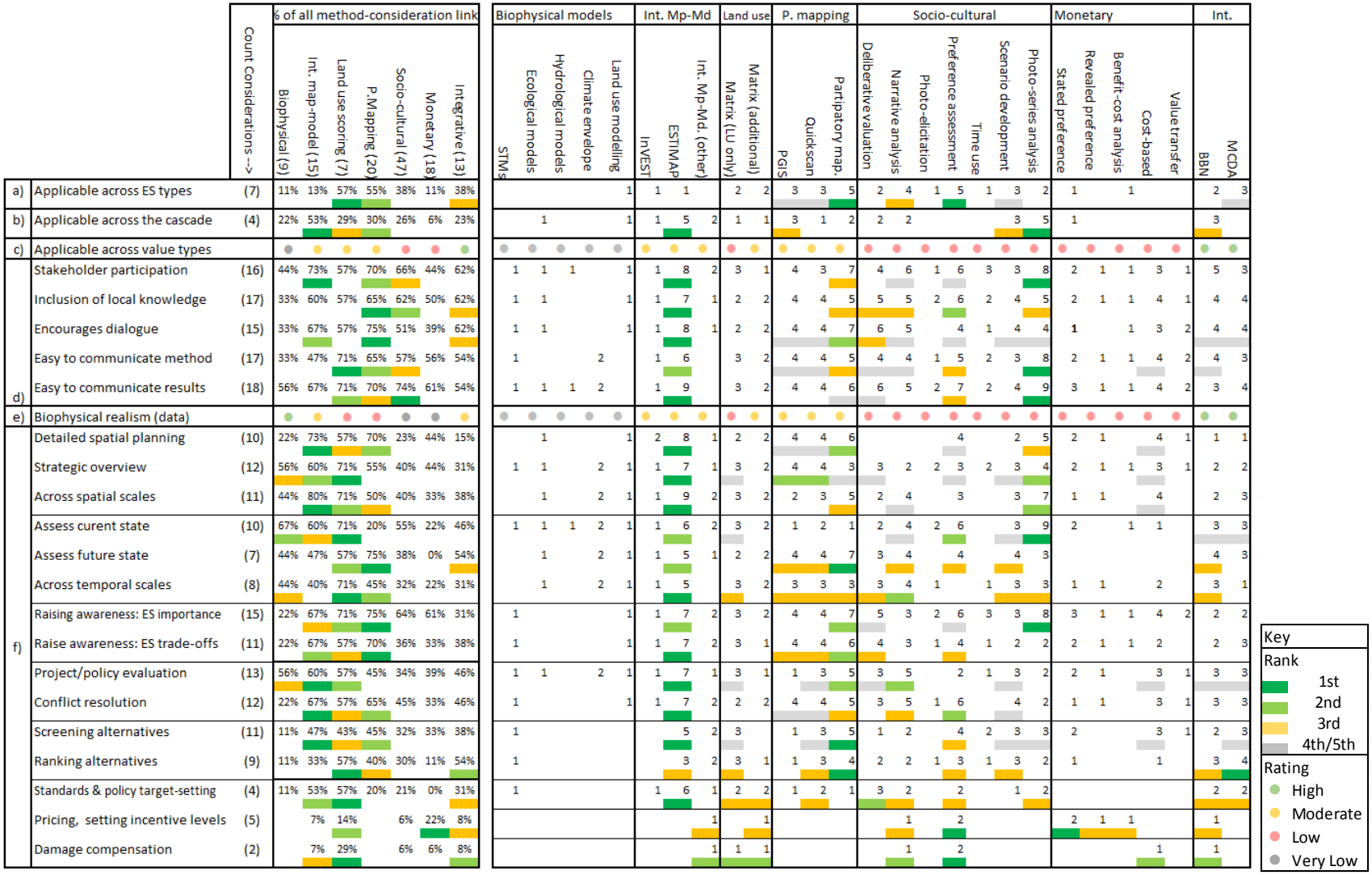


Figure 5: Overview of methods vs. considerations for selecting that method. The summary of the broad method classes (left) shows the proportion of the times the method was used where the consideration was seen as important. The summaries of the individual methods (right) show counts of the times the consideration was considered when selecting the method.

3.2.1 Selecting methods to address a range of different ES within a case study

Why is this important?

One of the primary advantages of the ecosystem service approach is its holistic approach to the natural environment (considering provisioning, regulating and cultural services). As such, having methods that can provide insights across the range of ecosystem services is a high priority to many practitioners: Figure 4a shows that 20 of the 24 OpenNESS cases cover the full range of ecosystem service types with at least one method in each type.

How was it addressed in the OpenNESS case studies?

For most of the case studies at least one method was selected because it was capable of addressing provisioning, regulating and cultural ecosystem services together. Other methods could then be combined with these approaches to focus on particular ecosystem services of interest such as cultural ecosystem services (Essex, Germany, Warwickshire); pollination services (Portugal, Barcelona) or soil erosion (Barcelona), or to address other priorities of the case study.

The broad range of methods used within OpenNESS to assess a cross-section of ecosystem services is shown in Figure 5a. Land-use scoring and participatory / deliberative mapping approaches were the main two method classes used for this purpose with "addressing the full range of ES" being selected as a consideration 57% and 55% respectively. The individual methods used most often were the three individual participatory mapping approaches (participatory mapping (5), QUICKScan (3) and PGIS (3)); three socio-cultural methods (preference assessment (5), narrative analysis (4) and scenario development (3)) and the integrative method MCDA (3).

However, in the Hungarian and Kenyan case studies methods were combined that each individually addressed different ecosystem service types. As an example, the Hungarian case assessed cultural ecosystem services using narrative approaches and preference assessment; provisioning and supporting services through participatory mapping, and regulating services using integrated mapping and modelling.

The fact that socio-cultural, integrative and land-use scoring approaches can all address a range of ES highlights that there are a range of different ways the suite of ES can be understood, from maps of quantified ES values through to stories of ecosystem service provision from in depth interviews with stakeholders or textual analysis.

3.2.2 Selecting methods to address different elements of the ES cascade

Why is this important?

In many cases it is important not only to know the state of the ecosystem in terms of its structure and the functions it performs (e.g. how much forest there is and how much it reduces flows to rivers) but to understand the services it supplies to people (reducing flooding), the demand for the service (number of people in the flood plain) and its value (e.g. avoided flood damage). As such, in many practical contexts it is important to have methods that can evaluate both ES supply and demand.

How was it addressed in the OpenNESS case studies?

Twenty of the 24 case studies contained methods capable of addressing ES supply and/or demand. Of these, all but three contained one or more individual methods which they selected due to their ability to address both supply and demand. As above, they then combined these with other methods which addressed other priorities within the case.

Integrated mapping-modelling approaches were most often selected for their ability to address supply and demand (in 53% of cases; Figure 5b) with other methods only selected for this reason in <30% of cases. The most commonly used individual methods were ESTIMAP and photoseries analysis (5 times each) followed by BBNs, participatory GIS and scenario development (3 times each). In the cases that did not highlight supply and demand as method selection considerations (Finland, Doñana and Romania), methods were used that could be applied to either supply or demand but these were focussed primarily on supply. In Doñana two methods capable of addressing either supply or demand were used separately to get an overview: MCDA was used to address supply whilst participatory/deliberative mapping was used to assess demand.

The methods used reflect very different potential understandings of supply and demand within a case. ESTIMAP, for example, can be used to map high biodiversity areas (ES supply) but also to model how accessible it is from nearby settlements (a proxy for ES demand). In photoseries analysis the photographs taken not only show the existence of the structure providing the service (e.g. an attractive forest) but also provide evidence that the service is being used (e.g. a human is enjoying the view enough to photograph it). For this reason cases often combine approaches to get more rounded views of the same issue (e.g. Cairngorms, Loch Leven: SM Tables 1 and 4).

3.2.3 Selecting methods to assess different aspects of value for ES

Why is this important?

There are many ways of classifying value (see IPBES, 2015) but here we focus on the three traditional classes of value: biophysical, socio-cultural and monetary (Gomez-Baggethun et al., 2016). The differences in how a problem can be understood through monetary units (e.g. price/ha timber), biophysical units ($MtCO_2e$ of carbon storage) and socio-cultural values (“I love forests”) exemplify the challenge of assessing the value of ecosystem services to human wellbeing. There was great interest within many of the case studies in ensuring

that a broad range of values were reflected beyond the monetary values often prioritised in decision making, particularly socio-cultural and biophysical values. Figure 4c shows that all but one case study selected methods that assess multiple types of value, and that 23 cases assessed both biophysical and socio-cultural values. Monetary valuation was applied in only eight cases.

How was it addressed in the OpenNESS case studies?

Values were assessed by combining different methods from across the overarching method classes illustrated in Figure 1. Eight cases combined at least one monetary method with a socio-cultural method and either a biophysical, integrated mapping-modelling or land-use scoring method to assess biophysical values. Of the other cases, all but four combined at least one of the three method classes for assessing biophysical data and at least one socio-cultural method. Furthermore, 19 of the 24 cases (Figure 3) used participatory/ deliberative mapping approaches which facilitate the capture of socio-cultural views and values (through their participatory nature) as well as being capable of capturing biophysical data related to the location and quality of ES-providing structures. Integrative approaches (BBNs and MCDA) were used in 13 cases as a means of integrated valuation: providing a mechanism to draw together, weight and make decisions using values from different sources in different units.

3.2.4 Selecting methods to reach different stakeholder groups

Why is this important?

In case studies where the ecosystem service concept is being put into practical use there will be a range of stakeholders with different levels of interest in, engagement with, agency over and dependency on the issue of concern. These stakeholders will draw their understanding of their environment and the specific case study problem from a range of different knowledge bases, both from scientific studies and from their own local knowledge and lived experience. For the ecosystem services concept to contribute to their understanding of the issue at hand, there is a need for methods that facilitate discussion and allow stakeholders with different types and levels of knowledge to engage with the assessment.

Within the OpenNESS cases there are a range of different examples of why this was necessary. In India, for example, there was a need to build understanding between local communities living in degrading forests and forest authorities managing the forests. In Brazil and Kenya there was a need to find methods to build understanding by people with different levels of formal education and familiarity with ecosystem services language and terminology. In Hungary and Finland, there was a need to build understanding between stakeholders, researchers with natural and social science backgrounds and practitioners with lived experience of the issues under study. In Patagonia, different methods were needed to communicate with land managers, researchers and local people.

How was it addressed in the OpenNESS case studies?

Most (22) of the case studies used methods that always include stakeholders actively within the process. The research teams identified five different aspects of stakeholder engagement that were considerations when selecting methods. These were: i) the method involved stakeholder participation; ii) the method facilitated the inclusion of local knowledge; iii) the method encouraged dialogue between stakeholders; iv) the method itself was easy to communicate and v) the results of the method were easy to communicate.

Facilitating stakeholder participation was scored as a major consideration across all method classes but particularly within integrated mapping and modelling (73%), participatory mapping (70%) and socio-cultural approaches (66%) (Figure 5d). Different method classes were selected to address different stakeholder-related aspects. Encouraging dialogue was a major consideration in the selection of participatory mapping approaches (in 75% of cases), and also for integrated mapping-modelling (67%) and integrative approaches (62%). However, land-use scoring approaches ranked highly for ease of explanation of method and results (71% for both). Inclusion of local knowledge was a consideration in 50-65% of cases for all method classes except for biophysical modelling (33%).

The individual method most commonly selected for stakeholder engagement considerations was ESTIMAP mapping-modelling (Zulian et al., 2014) which was modified within OpenNESS to facilitate greater stakeholder engagement. Photoseries, participatory mapping, preference assessment and deliberative and narrative approaches were also ranked highly, particularly with respect to the inclusion of local knowledge. Of these, photoseries ranked highly for ease of communication whilst participatory GIS and deliberative valuation (e.g. workshops) were commonly selected to stimulate dialogue.

3.2.5 Combining methods to address concerns with using a single method

Why is this important?

In a number of cases methods were combined as a response to other methods applied within the case (either before or after the method in question). This could be:

i) to provide inputs to (or receive inputs from) another method;
ii) to further develop the existing approach e.g. to improve its accuracy, or integrate aspects of other approaches;
iii) to triangulate findings between different methods to increase confidence or assess uncertainty in the results;
iv) to address another priority not addressed by the previously selected approach;
v) to follow up a subject of interest highlighted by the results of the previous approach;
vi) to respond to changes in the research/decision context or the stakeholder priorities;
vii) to attempt the approach at a different location, or at a different spatial scale or resolution; or
viii) to address perceived weaknesses in individual methods such as the level of robustness in the representation of biophysical reality.

Of these issues, i-vii) are discussed in section 3.3 which details the ways that methods were combined in practice within the cases. Here we focus on the final issue where a second method was applied to increase the level of biophysical realism within the case study. This is particularly important for biophysical methods, as the application of methods with weak links to ecosystem processes increases the uncertainty in ecosystem service assessments (Eigenbrod et al., 2010; Lavorel et al., 2017). As such, the level and detail of the biophysical data that underlies assessments influences the ability of a method to accurately represent ecosystem service provision. Lavorel et al. (2017) differentiate between five classes of biophysical method with increasing levels of biophysical realism: i) proxy methods – which use land-use data alone as the biophysical units from which ES are provided; ii) phenomenological methods: which integrate additional understanding of the biological mechanisms which underpin ES supply (e.g. landscape configuration, species type/richness, soil quality etc.) iii) niche- and iv) trait-based models that consider distributions and abundances of species or traits and v) full process models that explicitly represent ecosystems using mathematical formulations of ecological, physical and biogeochemical processes that determine the functioning of ecosystems.

How was it addressed in the OpenNESS case studies?

Figure 4e illustrates that whilst five cases used proxy-based methods to explore ecosystem services, none of these cases did so without an accompanying approach with a higher level of biophysical realism. Figure 3 shows that the cases using the matrix approach based on land-use data alone (the proxy method) combined this with the integrated mapping-modelling model ESTIMAP in Slovakia and Barcelona, species distribution modelling in Warwickshire, and an STM in the Carpathians. In Romania the method was combined with photoseries analysis: a socio-cultural approach that draws on observed, geo-located species data. Furthermore, in all cases the methods were combined with participatory GIS workshops as a means of triangulating evidence and adding richness to maps based on proxy data (see section 3.3.5).

3.2.6 Combining methods to address different stages of the research/case study's development (decision contexts)

Why is this important?

Within practical case studies different methods are needed at different stages of the "decision context", e.g. awareness raising, problem formulation, target setting and decision-making. This is important as the decision context determines the extent to which a combination of methods is seen as a "success" in the eyes of practitioners (see McIntosh et al., 2011; Dick et al., this issue). A number of decision contexts highlighted by the stakeholder assessments are discussed below including those related to i) spatial scale; ii) temporal scale; iii) awareness raising; iv) project evaluation and conflict resolution; v) deciding between alternatives and vi) developing policy instruments.

494
495 *How was it addressed in the OpenNESS case studies?*
496 Figure 5f shows the extent to which a range of different decision contexts were
497 considerations for method selection. In decision contexts related to spatial scale (e.g. for
498 detailed spatial planning; providing a strategic overview or looking at a question across
499 spatial scales), mapping approaches (integrated mapping and modelling, land-use scoring
500 and participatory mapping) were used. Of these, land-use scoring methods were commonly
501 selected for providing a strategic overview (71%); whilst integrated mapping and modelling
502 and participatory mapping were selected for detailed spatial planning (73% and 70%
503 respectively). Looking across spatial scales was a consideration for selecting integrated
504 mapping modelling (80%) and land-use scoring approaches (71%). Of the individual
505 methods, the spatially-explicit socio-cultural technique of photoseries analysis ranked highly
506 against all three considerations.
507
508 For decision contexts related to temporal scale, land-use scoring, biophysical methods and
509 integrated mapping and modelling ranked highest for assessments of the current state
510 (71%, 67%, 60% respectively) whilst participatory mapping methods were the preferred
511 methods for assessment of the future state (75%) followed by land-use scoring (57%) and
512 integrative approaches (54%). Land-use scoring ranked highest in relation to the "across
513 temporal scales" decision context (71%) followed by participatory mapping (45%) and
514 biophysical methods (44%). However, many individual socio-economic and integrative
515 methods were also used to address the cross-temporal consideration including narrative
516 analysis, scenario development, deliberative valuation, photoseries and BBNs.
517
518 Awareness-raising was highlighted as a consideration in over 60% of method uses within five
519 method classes (all except biophysical models and integrative approaches). For monetary
520 approaches, "raising awareness of ES importance" is the only consideration addressed in
521 >45% of method uses. All five approaches scored highly (>60%) for raising awareness of ES
522 importance, and participatory mapping and integrated mapping-modelling was also used
523 (>60%) for raising awareness of trade-offs between services.
524
525 Project evaluation and conflict resolution policy contexts were both considerations for the
526 selection of land-use scoring and integrated mapping-modelling (in >=55% of method uses).
527 Project evaluation was also a consideration in the selection of biophysical methods (56%)
528 whilst participatory mapping was selected to address conflict resolution (65%).
529
530 In decision contexts where alternatives are either screened or ranked, integrated mapping-
531 modelling, participatory mapping and land-use scoring were considered for screening (in 43-
532 47% of method uses), whereas integrative approaches were more often considered for
533 ranking (54% of method uses).
534

In the few case studies where development of policy instruments (standards/target setting; pricing/incentives; damage compensation) was a consideration, the most commonly selected approaches were land-use scoring, integrated mapping-modelling and integrative approaches. Unsurprisingly the "pricing/incentives" decision context was the only one in which monetary methods were the method class with the greatest proportion of methods addressing the consideration (22%).

Many of the case studies used an integrative method to draw together the results of the other methods applied in the case study. Also, 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, Portugal): these processes are integrative methods in themselves.

3.2.7 Additional factors driving method selection

Above we have discussed the major drivers for combining methods, according to the stakeholders. However a number of additional factors were shown to influence method selection (e.g. when deciding between two methods that assess cultural ES values). These included: a) practical constraints (time/resources and data); b) adapting to changes in circumstance ; and c) research interests of the case study teams.

Practical constraints (time/resources, data and expertise) tended to be most often mentioned with respect to certain methods that are recognised to be quicker/less data intensive than others, including participatory GIS, value transfer, cost-based methods, preference assessment, time use, expert-based mapping and photoseries analysis. In Barcelona, for example, limits on data availability and model scope led to the choice of expert-based mapping to assess soil erosion control, which was then combined with more sophisticated integrated mapping-modelling analysis of recreation and air quality using ESTIMAP. In addition, availability of expertise is a key factor both for identifying methods which link best to the actual context-oriented problem and for performing (technically) the required analyses. Within this context, ***adapting to changes in circumstance*** was often a factor influencing method choice. Factors such as changes in funding, staffing and access to expertise (e.g. visits from external experts see 3.3.2) led to changes methods selected for combination. In addition, ***research-related issues*** such as the interests, expertise and motivations of the research team also affected method selection (see 3.3.2) – this included academic curiosity in trialling a new method. Finally, the perception of methods as academically established and/or comparable with other studies also influenced method selection (see Harrison et al., 2017 for more on individual method considerations).

3.3 How are methods combined within practical cases?

The previous sections focussed on *why* different methods were combined to meet case study needs. Here we address *how* these methods were linked. Methods were linked in

many complex and different ways, including i) input-output transfers of data between methods, but also ii) transfer of ideas, concepts and learning; iii) methods development to customise them better to the context; iv) cross-comparison of method outputs for cross-checking/validation and v) linkages of method experience across contexts.

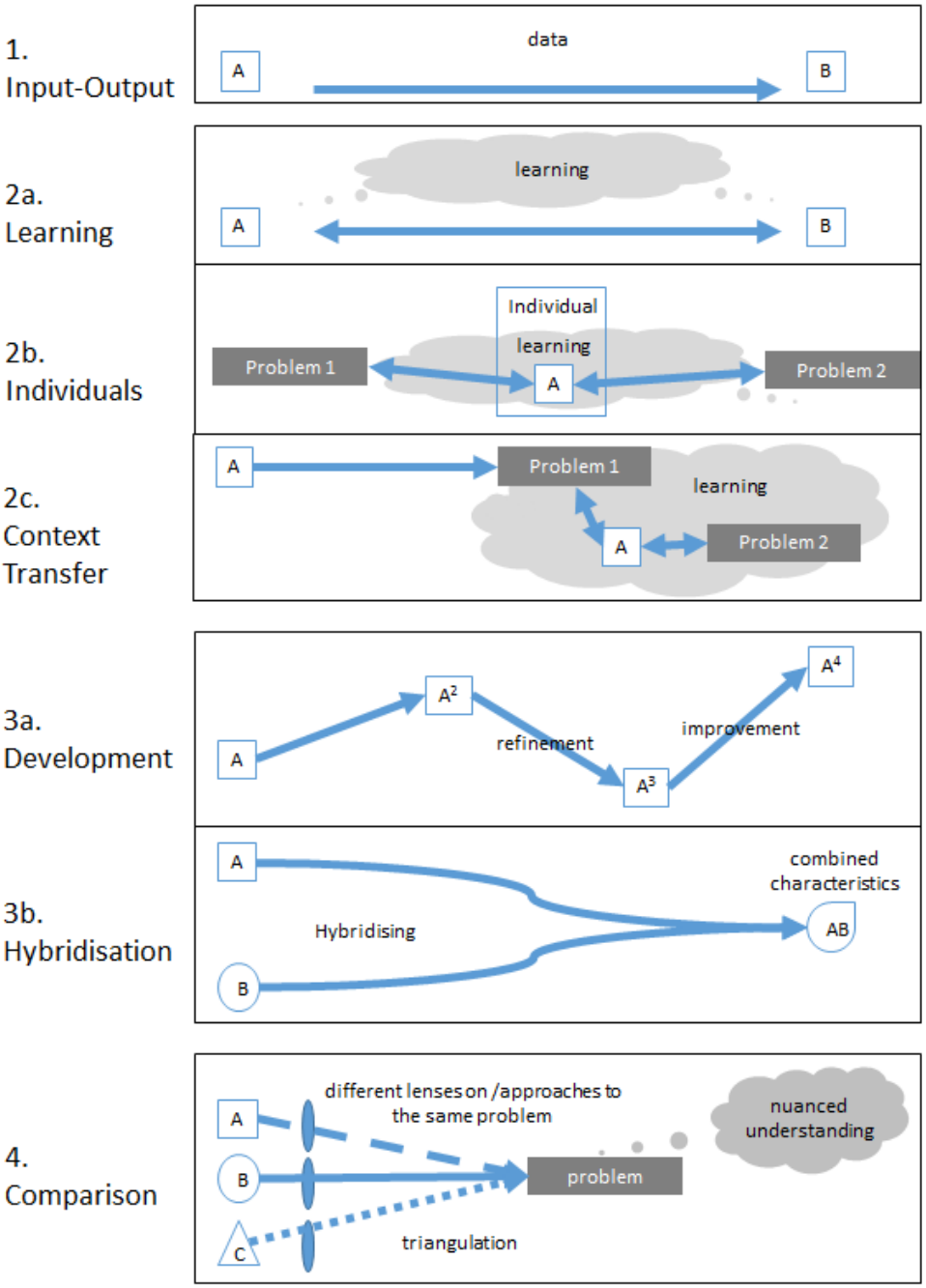
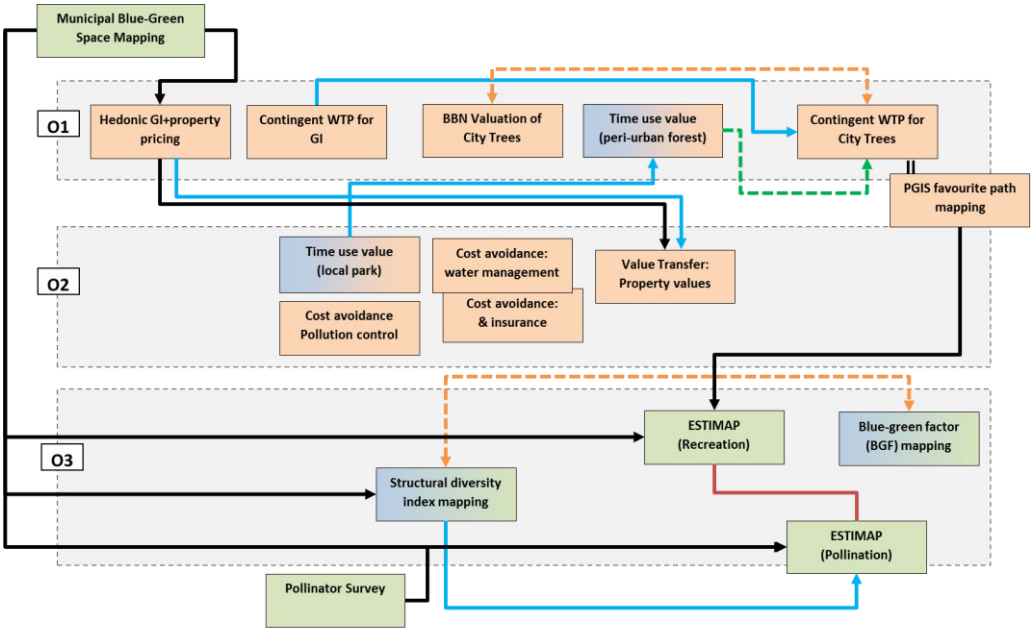


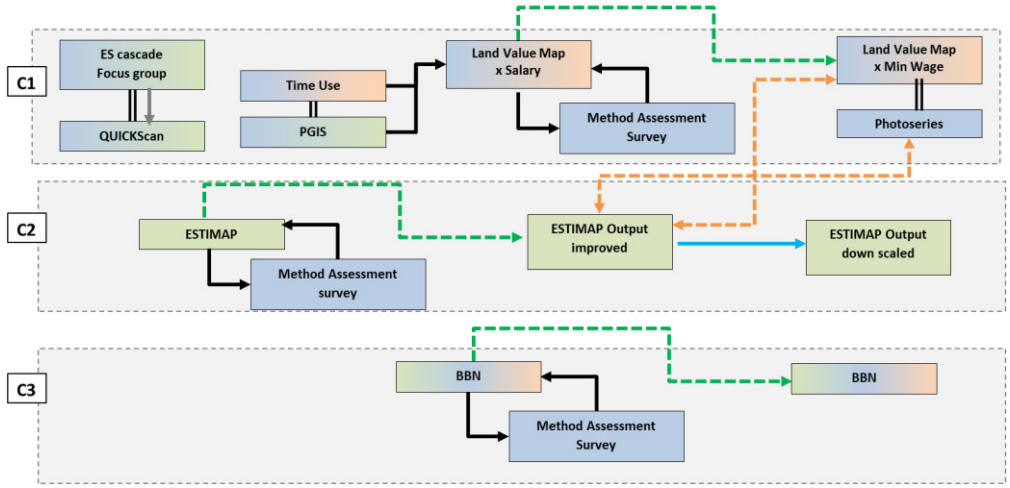
Figure 6: Linkage between methods identified within the OpenNESS case studies

Figure 6 illustrates the concepts behind the types of linkage. In the sections below we draw on experiences from across all 24 case studies (Table SM4) that demonstrate these different types of linkage, with particular reference to two examples: Oslo and the Cairngorms. Figure 7 provides a diagrammatic representation of how methods were linked within these two case studies to address their aims.

As for many of the case studies, tool selection in both cases was driven by these multiple goals related to different ES assessment issues. However, even where a specific aim was identified (e.g. Figure7a-O2), a number of different methods were combined to achieve it. The method types combined vary widely: O2 focuses almost exclusively on monetary approaches, whereas C1 combines aspects of biophysical, monetary and non-monetary approaches.



a) Oslo case study. Sub project aims: O1) to assess the monetary value of ES from Green Infrastructure at the city-scale; O2) to showcase local case study examples of the monetary value of ES to assist decision-making; and O3) to demonstrate the ability of the ESTIMAP tool



b) Cairngorms National Park case study. Sub project aims: 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

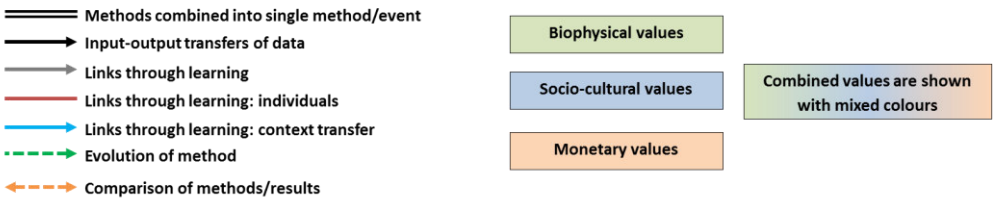


Figure 7a and b) Process diagrams of two example case studies Oslo, Norway and the Cairngorms National Park, Scotland.

3.3.1 Input-output transfers of data

Input-output transfers of data where qualitative or quantitative outputs from one method serves as the input to another were identified in 17 of the 24 cases (75%) although the

linkages themselves took a number of different forms. These included 1) primary data collection into other methods (e.g. water availability/soil data into spatial modelling in Hungary); 2) local knowledge collection as an input to mapping/modelling (e.g. in O1 PGIS to identify people's favourite walking routes was an input for recreational opportunities maps using ESTIMAP); 3) inputs to deliberative or integrative processes (e.g. ES mapping as an input to PGIS mapping in Belgium-De Cirkel or biophysical modelling inputs to MCDA in Finland) and 4) future scenario inputs to integrated modelling approaches (France , Germany).

Inputs may also come from methods outside the case study research, e.g. from existing datasets or prior research, including value transfer from other studies. In Oslo, for example, municipal blue-green space mapping by the Agency of Urban Environment forms an input to methods in both O1 and O3 (Figure 7). 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).

3.3.2 Links through learning

In some cases links between methods are less tangible and reflect broader learning resulting from prior experience with the method or its application (Figure 6-2a). All 24 case studies demonstrated some kind of learning as links between methods. Some cases deliberately selected methods to encourage learning: stakeholder workshops were often used to bring all participants to a similar level of understanding of ES concepts (e.g. prior to Quickscan in C1) or specialist language and terminology (e.g. Kenya). The Belgian-De Cirkel case study, reveals two important points. Firstly, that learning isn't always positive: stakeholders almost lost interest in the ES concept following the perception of a method being inapplicable scale of local interest. Secondly, many methods, particularly deliberative approaches, are specifically designed to maximise learning through developing shared understandings between individuals. In the De-Cirkel case a simple socio-cultural technique using ES-related photographs (the "ES card game") "confirmed the relevance" of the ecosystem services to the stakeholders and enabled future ES research to proceed.

Other method combinations stimulated learning between researchers and stakeholders across academic disciplines (e.g. the MCDA approach used in Finland stimulated transdisciplinary learning by bringing scientists from different backgrounds to work together see 3.2.4). Others still, selected methods following prior experiences with either the cases (e.g. Barcelona prioritised non-monetary approaches due to negative stakeholder reactions to market-based methods) or with the methods (e.g. Doñana selected methods to address gaps in values captured by previous methods). **Individuals, and the knowledge imbedded within them** play a key role in this process (Figure 6-2b), particularly those with methodological expertise. In the Oslo case study (O1), the monetary valuation expertise of the lead researcher was a key aspect driving both method selection and method application. Many case study teams' selection of method combinations was enabled by the availability

643 of methodological expertise (see 3.2.7). For example, close working relationships with the
644 lead ESTIMAP expert in both the Oslo and Cairngorms case studies encouraged the
645 development of the ESTIMAP methodologies in these studies, and the improved and
646 adapted method was then transferred to other case studies as described below. Case study
647 stakeholders and end users are also key links between methods: if the same stakeholders
648 remain engaged with the method development process this can help retain and facilitate
649 further learning (Saarikoski et al., 2017).
650
651 Learning also led to the **transfer of methods between locations and problems** leading to
652 new method combinations in the new context (Figure 6-2c). In the Oslo example, the time
653 use methodology initially developed at the local scale was later applied at the municipal
654 level (O2→O1) whilst the inverse was true for the hedonic pricing method (O1→O2). In
655 addition, contingent valuation was transferred from one topic to another at the same scale
656 (i.e. from a focus on all green infrastructure to a focus just on city trees). Photoseries
657 analysis was also widely transferred, being used in 11 of the case studies with learning and
658 expertise from one case encouraging the application in another (Table SM2). Method
659 transfer can stimulate method evolution (section 3.3.3). The ESTIMAP methodology, for
660 example, evolved considerably as a result of its application to different case studies. Initially
661 intended to be applied in a standardised manner customised at a European scale (Paracchini
662 etal., 2014), through testing across a number of OpenNESS case studies the methodology
663 was adapted to be applicable at much finer resolutions with successful application in both
664 national parks (e.g. Cairngorms; Costa Vicentina, Portugal) and urban areas (Oslo, Trnava,
665 Slovakia, Helsinki, Barcelona). This was not just a downscaling of the approach but an
666 evolution of the method from one based on standardised datasets to one that could be
667 customised to local needs.
668

669 ***3.3.3 Method evolution and development***

670 In 14 of the 24 cases, existing methods evolved into new and improved methods, or
671 progressively more advanced methods were applied. In some instances this was a natural
672 progression (Figure 6-3a). For example, in Slovakia, simple land-use scoring methods
673 (Burkhard et al., 2012) were improved by including stakeholder data from questionnaires
674 and additional environmental datasets, to evolve the method into an advanced approach
675 more akin to Greenframe (Kopperoinen et al., 2014). This was considered more scientifically
676 sound and suitable for the case study's planning purposes.
677
678 In eleven of the case studies, key aspects of different methods were combined to produce
679 **hybrid methods** (Figure 6-3b). In Oslo, a web tool was developed that combined
680 participatory mapping of favourite walking paths with a willingness-to-pay assessment of
681 the value of city trees. In the Cairngorms example C1, a socio-cultural method (time use)
682 was hybridised with monetary valuation and PGIS approaches to produce maps of land
683 value in terms of both time spent and monetary costs. In Patagonia, a deliberative workshop

was used to enable the research team and local experts to co-design and co-produce a biophysical State and Transition Model (STM) model that could be used to evaluate forest change. 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, a case study in the French Alps combined GIS tools with a BBN model of trade-off opportunities to produce a hybrid spatial BBN. This allowed forest managers to evaluate the spatial implications and trade-offs between forest production and conservation measures to preserve biodiversity in forested habitats (Gonzalez-Redin et al., 2016).

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), the hybrid time use/PGIS method was improved through the use of socio-cultural methods (a stakeholder survey) to assess stakeholder concerns with the method. In response, the monetisation approach was modified from an approach based on participant salary, to one based on the minimum wage as this was thought to be a fairer reflection of value. Similarly, learning between case studies can lead to the evolution of methods. PGIS approaches trialled in Warwickshire were modified when the method was transferred to Essex, based on case study learning that suggested that, in the local context, the approach used provided better responses when focussed on cultural ecosystem services (rather than provisioning/ regulating services).

In other cases innovative new methods were developed to address aspects particularly important to the case studies. For example, in Hungary 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 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, where there was limited available data on cultural services and many of the methods proposed within OpenNESS were unsuitable because they were customised for Europe, the case study developed the photoseries approach to map and quantify cultural services.

The key point is that approaches need to evolve dynamically and respond to feedback or new opportunities that arise within the case study; and that creativity and flexibility in combining approaches increase what can be achieved.

3.3.4 Method comparison

Method comparison was used in 17 of the 24 cases to produce more rounded understanding of i) the ecosystem services within the case study; ii) different aspects of the case study context iii) the value of ecosystem services from different valuation lenses (monetary, socio-cultural, biophyscical) and iv) the capabilities of individual methods. Triangulation of methods was a key aspect in encouraging confidence in case study results and in the identification of gaps for further research (see 4.1.3).

In O2 monetary valuation methods were used to both showcase the range of monetary tools available and highlight how they could be applied to understand different aspects of the case study context including different ES (e.g. recreation services, water and pollution management, aesthetic value). In the Cairngorms example, ESTIMAP (C2) and photoseries analysis (C1) provided a more rounded understanding of recreation ES: the first highlighting recreation potential based on spatial analysis of accessible nature whilst the other analysing geo-located photographs of locations people have actually visited and photographed nature. Comparing the two helped to identify where accessible nature is and isn't accessed, with the photographs providing additional information on the type of ES valued (e.g. aesthetic beauty, individual species or recreational events).

4 Discussion

We have drawn on 24 real world examples to illustrate which methods were used to meet case study priorities, why multiple methods were used, and how those methods were linked to add value to the case studies. In this discussion, we summarise the challenges and opportunities associated with combining methods, drawing on stakeholder questionnaire responses, and provide take-home messages for other practitioners.

4.1 Challenges and opportunities in combining methods

Many of the case studies stressed that the primary challenges and limitations were with the individual methods, but there are also a number of specific challenges related to using methods in combination.

4.1.1 Pragmatic concerns

Challenges faced

Practical constraints on time, cost, data availability and technical expertise (see section 3.2.7) led to challenges for case study teams combining multiple methods: challenges that increase with the technical complexity of the methods combined. Time demands may also increase as case studies adapt and evolve due to changing understanding of the issue at hand and/or changing stakeholder interests.

Successes and opportunities

There are an increasing number of networks, tools and training opportunities to help in selecting and applying new methods, including the OPPLA hub (www.oppla.eu) and the Natural Capital Protocol Toolkit (http://naturalcapitalcoalition.org/protocol/protocol-toolkit/). The OpenNESS case studies showed how face-to-face visits from method experts can strongly influence the successful uptake of a new method (3.2.7; 3.3.2). Echoing Jacobs et al. (this issue), combining tools to ensure that all the different aspects of an ecosystem assessment are addressed does not need to be prohibitively expensive, and can provide additional benefits by enabling more cost-effective management of natural capital.

4.1.2 Stakeholder-related

Challenges faced

Many of case studies faced challenges in working with stakeholders, particularly i) the logistical challenges of organising stakeholder engagement activities; ii) the challenges with finding (and maintaining) a large enough sample of stakeholders – which has impacts on the perceived scientific robustness of the approach (see next section); iii) the complicating factors of the local context, such as attitudes of particular stakeholders, local rivalries and people changing roles (see also 3.3.2); iv) issues related to whether the results are repeatable/reproducible (see below) and v) challenges that resulted from stakeholders driving method selection and setting the decision context (see also Saarikoski et al., 2017).

Successes and opportunities

Including stakeholders in participatory processes allowed increased engagement in a number of cases (e.g. Patagonia's participatory BBN and India's participatory field work method, SM4). Furthermore it led to real-world impact in a number of cases. For example, in Slovakia the OpenNESS case study ensured that a more accurate and scientific assessment of ecosystem services was implemented, and increased the environmental awareness of stakeholders with respect to the importance of ecosystem services. This led to an improvement in the decision-making processes around land management which now recognise factors that encourage and discourage the use of ecosystem services. In France, the OpenNESS results will provide inputs to the next regional rural development planning exercise in the French Alps.

4.1.3 Scientific robustness and reproducibility

Challenges faced

Subjectivity is recognised as a fundamental aspect of all research, and scientific rigour is achieved by ensuring that methods are applied in a robust, transparent and repeatable manner. This poses challenges for a number of ES assessment tools. For participatory methods, for example, case studies cited the difficulty of selecting a representative sample of stakeholders and replicating and validating the outputs (4.1.2). Challenges also arise in assessing intangible cultural ecosystem services such as aesthetic value, which reflect subjective views of the beneficiaries. Biases can arise from the use of social media-based approaches such as photoseries analysis due to limitations in the breadth of the user

community (e.g. Flickr users). Scenario methodologies make assumptions based on how the future will evolve. It is important to recognise that combining multiple methods may lead to aggregation of these uncertainties, especially for methods combined in an input-output link (3.3.1) or transferred across contexts (3.3.6).

Successes and opportunities

Many of the case studies reported that comparing multiple methodologies (3.3.5) can help to address problems with the robustness of individual methods through "triangulation" of results (e.g. Cairngorms, Essex, France, Loch Leven, Portugal, Warwickshire). Investigation of the similarities and differences between multiple methods can be time-consuming, but it does add value through improving understanding of the strengths and weaknesses of the methods applied, and targeting areas for further research and method development. Nevertheless, it is important to ensure that triangulation does not create a mis-placed sense of confidence in results obtained with multiple methods.

OpenNESS research was framed as place-based and problem-focused work (post-normal science), where the research process was equally driven by local stakeholders and scientists. This required considerable flexibility and adaptability on the part of the research teams. Reproducing such a process would only be possible if the same problem was investigated in the same locality with the same stakeholders. However, this is meaningless where the aim is to solve real life problems. Rigour can be enhanced by encouraging iteration and feedback with relevant stakeholders and external experts, and by building on the findings of previous published studies. In OpenNESS, stakeholder-led case study advisory boards provided this "validity check" function, by discussing the results and raising any concerns that required further investigation of modifications to methodology.

The use of multiple methods also poses challenges where there is a need for comparable, standardised approaches at national or international levels, such as the EU MAES process (Mapping and Assessment of Ecosystem Services, Maes et al., 2013) and the UN SEEA EEA (System of Environmental and Economic Accounts – Experimental Ecosystem Accounting, UNSD 2014). Where possible, comparability should be facilitated by linking methodology to existing standards. Tools such as translation keys to link the ES terminology used in case studies to standard ecosystem service lists (e.g. Common International Classification of Ecosystem Services: CICES), the use of transferable methods (such as InVEST and ESTIMAP) and protocols for a common blueprint for ES studies (Seppelt et al., 20212) may assist with this.

4.1.4 Combining disparate methods

Challenges faced

We have illustrated the benefits of combining a wide variety of ecosystem service tools in different ways, to tackle complex real-world problems that require interdisciplinary

approaches to encompass a range of values, services and stakeholders. But this is not to say that every tool can be combined with every other tool without overcoming significant differences in methodology.

Practical challenges are associated in combining methods that differ in the services addressed, types of values captured, level of biophysical realism, measurement and output units, spatial units and scale of the analysis. Comparing biophysical and socio-cultural research outputs was a challenge in many of the cases (e.g. Hungary, Slovakia, Sierra Nevada) as not all outputs "fit together". For example, geo-located social media photographs and questionnaire responses both bring useful insights but it is challenging to combine the two into a single integrated result (Patagonia). These kinds of challenge are particularly pertinent for input-output (3.3.1) linkages and for cases where comparison for validation (3.3.4) is considered. Linking methods with very different levels of scientific complexity can also inhibit transfer of learning (3.3.2). In the Finland case, for example, it was clear that BBNs can become very complicated: it takes a lot of effort to fill in probability tables and this can lead to stakeholders losing interest.

In addition to methodological challenges there are also epistemological and ontological challenges (Vatn, 2009). Biophysical, monetary and socio-economic methodologies stem from very different disciplinary backgrounds with different epistemological stances on what constitutes robust knowledge, and ontological stances on whether robust knowledge is possible (4.1.3). It can therefore be very challenging for researchers from different backgrounds to work together, and thus to combine methods from these different disciplinary origins.

Successes and opportunities

Despite these significant challenges, 63% of the OpenNESS research teams stated that the combinations of methods used within their case studies had met their needs, whilst the remaining 37% replied with a qualified affirmative (reflecting the challenges discussed in this section). The OpenNESS case studies highlight the importance of flexibility and creativity when it comes to practical ES assessments, and all research teams stress the importance of embedding stakeholder engagement within the core of the research process. Many methodological challenges can be overcome with sufficient time, resources and expertise (e.g Dick et al, 2016; Garcia Liorente et al., 2013. GIS skills are particularly useful in this regard (Oslo). Ontological/epistemological concerns can also be addressed. Interdisciplinary approaches do take time to find common ground, but research teams reported that they ultimately fostered a collaborative atmosphere between different scientific disciplines and also between researchers and non-researchers, as it was clear that the scientists were also learning from the process (e.g. Hungary, Belgium-Stevoort, Finland; Saarikoski et al., 2017). Whilst differences in ontology/epistemology should not be overlooked, practical deliberative approaches such as workshops, meetings, presentations and informal

discussions with stakeholders that incorporate an awareness of the strengths and limitations of different methods can help to integrate disparate methods into a coherent output even in the absence of shared units or a common spatial framework (Essex, Warwickshire, Hungary).

4.1.5 Scale

Challenges faced

A number of case studies reported challenges related to scale, spatial extent and spatial resolution. Working at large scales (e.g. large regions, national, international) leads to challenges for validation, particularly of social science methodologies, and increases the challenge of convening representative stakeholder groups (Hungary, Essex, Brazil). Both fine and broad scales can pose challenges for obtaining datasets at the right spatial resolution (Barcelona). Some methods are more appropriate for certain scales (e.g. the Cairngorms case found ESTIMAP to be appropriate for the national park scale, but too coarse when zoomed in) and method scale can limit utility for particular decision needs (e.g. see 3.2.6). Spatial extent may need to vary to cover different ES. In the Portuguese case, the default case study boundary needed to be extended to cover the spatial extent of marine ecosystems and pollination services relevant to the study.

Successes and opportunities

Whilst data availability can be a key constraint, in many cases spatial challenges can be resolved with the application of resources and expertise, particularly GIS skills which facilitate the transfer of datasets between scales (Oslo). There are many cases where methods were successfully combined at the same scale (e.g. Loch Leven, Warwickshire) or adapted to transfer across scales (e.g. Barcelona, Helsinki, Oslo; 3.3.2). Methods can be combined to make up for deficiencies in spatial resolution. For example, the Cairngorms case study combined local surveys that were impossible to conduct at the national park level with integrated mapping-modelling that was suitable only at a broader scale. With sufficient time, methods can be nested and cross-scale approaches can be taken (Patagonia, Sierra Nevada; Martin-Lopez et al., 2017). Cross-scale approaches can be very important for integrated valuation as values can vary with spatial resolution, because of the level of aggregation and the spatial context. For example, the individual value of a street tree is different to the value of a similar tree in a park or forest (Oslo). Even where spatial challenges persist, e.g. for methods linked by input-output data (3.3.1) and direct-overlay comparisons (3.3.4), they can contribute to case-based learning (3.3.2) by allowing stakeholders a more nuanced understanding of an issue.

4.2 Take-home messages

Some of the details identified above will reflect the particular features of the OpenNESS project, but the key messages are transferable to any ecosystem services assessment. In this

section we summarise key messages for practitioners concerning the selection and combination of methods.

4.2.1 Why use combinations of methods in ecosystem service assessments?

There are a wide variety of ecosystem service assessment tools available, and an increasing number of approaches to help users decide which tool to use (Harrison et al., 2017; OPPLA). However, this paper demonstrates that assessments can be strengthened by combining a number of different methods. This can yield the following benefits.

- Individual tools are unlikely to address all the needs of a given context, but a range of approaches can be used to assess different aspects of ES, such as different types of green infrastructure, different groups of services, different geographic scales or timescales, and different types of value (e.g. biophysical, socio-cultural and monetary);
- Certain tools, especially deliberative tools such as workshops, can be used to transfer knowledge, concepts and ideas amongst researchers, local experts, specialists and stakeholders, which can facilitate uptake of ecosystem service concepts and thus enable the implementation of additional tools such as biophysical models;
- Valuable learning and opportunities for model improvement can be gained by transferring methods across projects at different scales or locations.
- Combining methodologies into hybrid approaches helps to overcome weaknesses in the individual approaches, e.g. including local ecological knowledge or specialist expertise in biophysical models;
- Hybrid approaches or evolutionary development of existing tools can increase analytical capability or reduce uncertainty, e.g. combining the trade-off analysis of a BBN with the spatial analysis and visualisation of a GIS mapping tool to create a spatial BBN;
- Drawing flexibly on a range of methods can allow new methods to be deployed in response to changes in the focus of the project;
- Applying multiple methods can allow cross-comparison, thus providing an indication of the level of uncertainty in the assessment and potentially highlighting biases or weaknesses in the approach;

4.2.2 What methods should be combined?

There is no one-size-fits-all solution to ecosystem services assessment, and it is beyond the scope of this paper to provide definitive guidance on which tools to combine, as this will depend on the case study context. However, it is clear that 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) Set-up. Identify a representative stakeholder group; convene an advisory board to ensure robustness; and assess user needs. This will require socio-cultural techniques (surveys, workshops, interviews, etc.) and there are a number of tools

that can be used within these to enrich the information content of the process (e.g. the ES card game). *Be prepared to iterate throughout the process.*

Step 2) Scoping. Use quick, simple methods to build an understanding of the issue, e.g. land-use scoring; participatory mapping. These low-cost and informal methods can also provide an opportunity to start building mutual understanding and a shared language between stakeholders and researchers from different disciplines.

Step 3) Evaluation. Use a combination of monetary, socio-cultural, mapping and modelling methods to meet the needs of the case, ensuring that the chosen approaches reflect the range of different values that stakeholders hold (see Jacobs et al., this issue). The level of biophysical realism that can be applied will depend on the needs of the case study, the time and budget, and available expertise. Visits from method experts can be invaluable. Applying multiple methods to address the same problem can help with assessing uncertainty, enhancing understanding and building confidence in the results. Periodic review by the advisory board can help to ensure robustness and identify potential method improvements. A flexible and creative approach may allow methods to be improved and hybrid or novel methods to emerge in response to new information or stakeholder feedback.

Step 4) Integration. Use an integrating approach to draw the different assessments together. This need not be complex or numerical: it could be a deliberative workshop with the relevant stakeholders drawing together the outputs from the different methods.

5 Conclusion

This paper has demonstrated the range and variety of methods applied in ecosystem service assessment in 24 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. Combining different methods can greatly strengthen ES assessments, allowing them to address the full range of relevant ES and value types, engaging different stakeholder groups, highlighting areas of uncertainty, building a deeper understanding of the socio-ecological system, and facilitating method development and learning. However there are a number of challenges to be addressed, including practical constraints on time, resources and expertise, and the difficulties of interdisciplinary working. Successful application of combined methods will require a good understanding of the strengths and weaknesses of individual methods, and maintain a flexible and dynamic approach that can respond to opportunities and constraints as they arise.

Whilst the complexity of socio-ecological systems and the competing demands for nature's goods and services present major challenges for ecosystem management, the case studies presented here demonstrate how ecosystem service assessment methods can be combined in innovative and creative ways to create customised solutions that address practical user

needs. By sharing and learning from the experiences of stakeholders, practitioners and researchers from different disciplines (e.g. via the OPPLA hub), we can ensure that these innovative approaches diffuse quickly and enhance our options for sustainably managing the services our ecosystems provide.

Acknowledgements

This research was funded by the European Union EU FP7 project OpenNESS (Grant agreement no. 308428). The OpenNESS project is solely responsible for the content of this publication. It does not represent the opinion of the European Union, nor is the European Union responsible for any use that might be made of information appearing herein.

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Supplementary materials

Table SM1: Overview of the 24 OPENNESS case studies within this paper (Colours reflect the case study groupings). Information on case study "issue" from Wijnja et al., 2016. For further Case Study information including more detail on the study area, what was done and achieved within OPENNESS, and lessons learned from the cases see Wijnja et al., 2016.

Country	Case Study	Detail on case study and explanation of why method combinations were required.
Belgium	De Cirkel	**Reconciling land consolidation and multifunctional agricultural landscapes: Project De Cirkel (Limburg, Belgium)** **Issue:** De Cirkel is a farmland conservation project aimed at improving agricultural efficiency in the Jesseren area. Some less productive land (150 ha) became available and was reserved for nature development. The challenge was to find efficient, sustainable and widely supported ways to implement and manage the planned green corridors in the agricultural landscape. **Why combine methods:** Interested in applying two tools in parallel to explore the issue in question with stakeholders. The two tools were combined as one focussed on supply whilst the other focussed on demand. Demand was the initial interest and was used to cross-check the supply. **Case Study group: Mixed Rural Landscapes**
Belgium	Stevoort	**Integration of ecosystem services in the planning of a flood control area in Stevoort, Belgium** **Issue:** The project area of Stevoort (150ha) is a designated flood control area located in the city of Hasselt (Flanders, Belgium). It is part of a wider valley around the rivers Herk and Mombeek and their tributaries. In order to gain local support for developing a flood control area, local and societal needs had to be taken into consideration, as well as possible adverse effects. **Why combine methods:** Methods were combined as there was an awareness amongst some of the researchers involved in the case study of the possible limitations and added value of particular ES-tools, their complementarity, etc… (including potential pitfalls of top-down ES-mapping/modelling). We had quite a good view on the potential benefits of a mixed-methods-approach in order to get the most out of the ES-results (taking into account local project goals: for example in terms of social learning). **Case Study group: Integrated river basin management**
Brazil	São Paulo region	**Biofuel farming and restoration of natural vegetation in the São Paulo region, Brazil** **Issue:** Brazil is the biggest producer and user of ethanol originating from sugarcane, most of which is grown in the Sao Paulo region. Under Brazil's Forest Code law, every rural property in the region must preserve 20% of its native vegetation area, as well as forests alongside streams. The law envisages payment for ecosystem services maintained by farmers so the feasibility of such a scheme had to be determined. **Why combine methods:** Methods were combined to reach different stakeholders (with different levels of education and understanding) and to answer different questions (e.g. How much should be paid for ESS or what institutional arrangements would be needed for it). **Case Study group: Commodity export dominated areas in developing countries**

England	Warwickshire	**Tools for investigating biodiversity offsetting in Warwickshire, England** **Issue:** This case study explores tools to identify the potential for biodiversity offsets (where developers agree to restore habitats elsewhere to compensate for those lost or damaged) to protect natural capital and ecosystem services, and the resilience of offsets in the face of climate change. **Why combine methods:** To showcase the range of tools that could be used to understand ecosystem services. To reduce uncertainty to see which tools reinforce each other and which don't. To establish the strengths and weaknesses of the different methods. **Case Study group: Mixed Rural Landscapes**
England	Essex	**Ecosystem service mapping in Essex, England** **Issue:** Essex is close to London and demand for housing is driving the loss of green space. This case study explored methods for demonstrating the value of natural capital and ecosystem services as assets to the community, to counterbalance the threat from development. **Why combine methods:** Run in tandem with Warwickshire case by the same research team. Same purpose for method combination **Case Study group: Mixed Rural Landscapes**
Finland	Helsinki	**Operationalising ecosystem services in urban land-use planning in Sibbesborg, Helsinki Metropolitan Area, Finland** **Issue:** The objective of the case study was to explore how ecosystem services can be integrated into the land-use planning process to better achieve sustainability goals. The focus was on multifunctional green infrastructure and applying new tools to operationalise ecosystem services in a participatory way. **Why combine methods:** The two methods used, PGIS approach and ESTIMAP analysis complemented each other in the case study research **Case Study group: Sustainable urban management**
Finland	Finland	**Forest bioenergy production in Finland** **Issue:** In the forest sector, the increasing demand for bioenergy production poses a challenge for sustainability. The case study focusses on assessing, together with stakeholders, the short- and long-term impacts of forest bioenergy production on the provisioning of ecosystem services. **Why combine methods:** The research process started with a participatory MCDA process to structure the assessment (i.e. the scenarios and criteria to be assessed). Biophysical (BD, carbon sequestration, water quality, energy) and socio-cultural (recreation, landscape) assessments were carried out to evaluate the impacts of forest bioenergy production in Hämeenlinna case study area. A weighing process was carried out as part of MCDA with the involved stakeholders to assess the trade-offs related to ecosystem service provision in alternative forest bioenergy scenarios. The MCDA process revealed several uncertainties in the biophysical assessment. Due to the uncertainties, the research team decided to use BBN which can make use of expert judgements about the probability of changes in forest ecosystems. **Case Study group: Management of forests/woodlands**

France	French Alps	**Operationalising ecosystem services in regional and national forest management planning in the multifunctional landscape of the French Alps** **Issue:** The National Forestry Office and other regional stakeholders wish to target management options for the French Alps region to support stakeholders and policymakers in reconciling biodiversity conservation with the increased demands of natural resources, especially in managed forests. **Why combine methods:** A multifunctional approach was needed. The combination of different methods answered to different objectives, helping to identify knowledge gaps in terms of economically and ecologically viable alternative to management options needed in answer to French policies **Case Study group: Management of forests/woodlands**
Germany	Saxony	**Bioenergy production in Saxony, Germany** **Issue:** There was a need to assess how current and expected future land-use changes affect the synergies or trade-offs between bioenergy production and other ecosystem services, e.g. to assist Germany in its aim to increase renewable energy provision up to 35% by 2020. **Why combine methods:** Combining integrated modelling and scenario analysis is a successful and well established strategy to assess current conditions and potential futures of socio-environmental systems. As cultural ecosystem services (CES) are often neglected and difficult to address with the above mentioned methods , we developed a new smartphone-based tool to support or replace conventional paper-based surveys **Case Study group: Mixed Rural Landscapes**
Hungary	Kiskunság	**Supporting sustainable land-use and water management practices in the Kiskunság National Park, Hungary** **Issue:** Since the 1970s, Kiskunság has suffered from a considerable drop in the groundwater table. Water availability now has a strong impact on local agriculture and natural habitats. The case study aimed to lay the basis for the resolution of water management conflicts. **Why combine methods:** Only the combination of methods of natural and social science led to reliable maps. Different methods were assigned to each step of the long assessment process. Preference assessment method was the prerequisite of each assessment process. From a valuation perspective the combination of methods seemed necessary to be able to grasp various value types and to bring in different stakeholders' voices. **Case Study group: Mixed Rural Landscapes**
India	Bankura and Sundarbans	**Participatory biodiversity management for ecosystem services in Bankura and Sundarbans, India** **Why combine methods:** There was a need to build understanding between local communities and forestry staff. An approach needed to be developed that could identify sources of degradation and highlight alternative livelihood opportunities using simple but scientific criteria. Methods were combined that encouraged the inclusion of local knowledge in situ. **Case Study group: Commodity export dominated areas in developing countries**

Italy	Gorla Maggiore	**Nature-based solution for water pollution control in Gorla Maggiore, Italy** **Issue:** This case study tests the feasibility of green infrastructure (constructed wetlands) instead of traditional grey infrastructure to treat combined sewer overflows by considering the multiple benefits (ecosystem services) provided by the green infrastructure and its relevance for water management. **Why combine methods:** Methods were combined to cover different aspects of the integrated valuation of ecosystem services (biophysical quantification, monetary and non-monetary valuation, MCA) **Case Study group: Integrated river basin management**
Kenya	Kakamega	**Operationalising ecosystem services for improved management of natural resources within the Kakamega Forest, Kenya** **Issue:** Ecosystem Services are increasingly gaining attention globally in natural resource planning, yet the concept is still poorly understood. The overall goal was to create awareness of the ES concept by conserving the Kakamega Forest ecosystem through a sustainable development approach so as to promote multiple ES and support both support human economy and well-being. **Why combine methods:** Methods were combined to address different research questions and stakeholder needs/interests raised throughout the stakeholder process. They were also combined for data transfer (from one method to the next) and for validation of results identified. **Case Study group: Commodity export dominated areas in developing countries**
Norway	Oslo	**Valuation of urban ecosystem services in Oslo, Norway** **Issue:** Among the cities of northern Europe, Oslo has the highest population growth as a percentage of total population, and its green spaces are facing significant pressure from development. It was necessary to raise awareness of the importance of urban ecosystems and to improve knowledge about the potential and limitation of ecosystem services and natural capital in order to support urban management and decision-making in the city. **Why combine methods:** The reasons for combining methods include providing inputs from one method to another, learning from the outputs of previous models and with experience of the case and by transferring methods from one context to another. An implicit reason for combining methods is the disciplinary composition of the case study team revealing some combinations of methods more easily than others. In our case, combinations of monetary valuation methods were more likely. **Case Study group: Sustainable urban management**
Patagonia	National	**Retention forestry to improve biodiversity conservation and ecosystem services** **Issue:** To quantify the impacts of traditional forest management on biodiversity and ecosystem service values and develop new forest management strategies using the retention capacity of the forest. **Why combine methods:** Methods were combined for two main reasons: (a) different scale analyses (e.g. al landscape level using biophysical modelling, and at stand level using State and Transition models); (b) some methods are more easy to transfer to the producers, and some methods are only understood by the researchers. **Case Study group: Commodity export dominated areas in developing countries**

Portugal	Costa Vicentina	**Operationalising ecosystem services in the Sudoeste Alentejano e Costa Vicentina Natural Park, Portugal** **Issue:** The Natural Park faces pressures from the depletion of natural capital stocks and increased tourism. Policies and planning instruments are needed that ensure the sustainable management of stocks and the delivery of ecosystem services, while promoting the well-being of the local population. Local stakeholders and decision makers should be engaged throughout the process. **Why combine methods:** The CS started without any previous information or work on ES done in the area. Methods were combined in an iterative and sequential process, where we started by using photo-elicitation surveys to identify main ES and landuses in the area (in a sort of scoping exercise). Then we used expert/GIS and participatory mapping as two complementary sources of information to get an overview of the spatial distribution of ES in the CS area. Finally we used ESTIMAP and photo-series analysis in order to get a more refined mapping of pollination and recreation (ESTIMAP) and cultural (photoseries) ES. In conclusion, the reasons for combination were: scoping, refinement and validation of results. **Case Study group: Coastal area management**
Romania	Carpathians	**Forest management in the Carpathian Mountains, Romania** **Issue:** Pressures from inappropriate forest exploitation and tourism infrastructure in Bucegi National Park can significantly impact forest ecosystems and human well-being. Ways need to be found to support local communities and their traditional activities by identifying ecosystem services and their links to biodiversity and forest ecosystem functioning. **Why combine methods:** We chose the methods based on the case study needs and stakeholders wishes. Their combination seemed logical taking into account our experience with the case study and expert's opinions within the OpenNESS consortium. **Case Study group: Management of forests/woodlands**
Romania	Romania	**Operationalising ecosystem services for an adaptive management plan for the Lower Danube River, Romania** **Issue:** The Lower Danube River Wetlands System has changed significantly, and now consists mainly of mono-functional agricultural ecosystems. This has led to a decline in ecological functions and, consequently, to the loss of benefits and ecosystem services. There is a need to enhance the effectiveness of integrated and adaptive management planning and implementation by mainstreaming understanding and operational tools related to concepts of natural capital and ecosystem services. **Why combine methods:** Methods were combined to improve the operational infrastructure dealing with valuation of ecosystem and landscape services, aiming for integrated and adaptive management of nested socio-ecological systems in the lower Danube river (Romania) **Case Study group: Integrated river basin management**

Scotland	Cairngorms	**Improved, integrated management of the natural resources within the Cairngorms National Park, Scotland** **Issue:** The aim was to enhance the management of the natural resources within the park for the benefit of visitors, local people and biodiversity. This requires the involvement of managers and residents in designing integrated land management planning for the economic development of the area while balancing the needs of biodiversity. **Why combine methods:** Methods were combined to provide additional knowledge for decision making. They built on suggestions of the local stakeholders and in response to feedback within the case study. Furthermore we took advantage of expertise available in the consortium to trial new methods. **Case Study group: Mixed Rural Landscapes**
Scotland	Loch Leven	**Quantifying the consequences of the European water policy for ecosystem service delivery at Loch Leven, Scotland** **Issue:** The goal was to enhance the management of the natural resources within the Park for the benefit of visitors, local people and biodiversity. This requires the involvement of managers and residents in designing integrated land management planning for economic of the area while balancing the needs of biodiversity. **Why combine methods:** BBN & ESTIMAP methods focused on different services and were not combined. Photo-series was used specifically to get weights for the ESTIMAP model **Case Study group: Integrated river basin management**
Slovakia	Trnava	**Landscape-ecological planning in the urban and peri-urban areas of Trnava, Slovakia** **Issue:** Trnva is experiencing environmental problems due to urbanisation. The study aimed to develop and test usable methods for the valuation of selected ecosystem services at the local and regional level and to promote their incorporation into spatial planning and decision making in Slovakia. **Why combine methods:** Methods were combined to obtain the most accurate assessment of the potential of the territory for the provision of ecosystem services suitable for planning purposes, Comparing, harmonizing the scientific outlook for the assessment and use of ecosystem services with the view of the managers and users of the territory, **Case Study group: Sustainable urban management**
Spain	Sierra Nevada	**Ecosystem services in the multifunctional landscape of the Sierra Nevada, Spain** **Issue:** Strict conservation practices can lead to rural abandonment, land-use intensification and social conflicts. The aim was to assess whether the ecosystem service approach can be used as a tool for the management of protected areas. **Why combine methods:** Methods were combined: (1) To elicit different values of ecosystem services hold by multiple stakeholders. (2) To comprehend the different understandings about the contributions of nature to human wellbeing by the different stakeholders, (3) to answer new questions that emerge as a result of a former research **Case Study group: Mixed Rural Landscapes**

Spain	Doñana	**Operationalization of ecosystem services in the cultural landscapes of Doñana, south-west Spain** **Issue:** Territorial planning in Doñana has often resulted in conflicts between conservation authorities and resource users, with negative consequences for biodiversity and ecosystem services. The aim was to explore ways in which ecosystem services can be incorporated into the management of the surrounding landscape of the protected areas of Doñana. **Why combine methods:** Methods were combined to address different but sequential questions related to traditional vineyards. Firstly, methods were selected to assess the ES vineyards provided to local people. Then, we moved on to assess how the vineyards could be protected from decline by drawing on in depth local knowledge of stakeholders though workshops. **Case Study group: Coastal area management**
Spain	Barcelona	**Mapping ecosystem services to inform landscape planning in the Barcelona metropolitan region, Spain** **Issue:** A key challenge of landscape planning is coping with multiple ecosystem service potentials and demands in complex socio-ecological systems such as urban regions. The main aim of the case study was to foster sustainable landscape planning in the Barcelona metropolitan region using ecosystem service maps as a decision support tool. **Why combine methods:** Case study purpose was to provide (spatial) information on ES. Different methods were needed in order to provide a fairly comprehensive overview of ES provision and demand in the area. **Case Study group: Sustainable urban management**

1166 ***Table SM2: Methods used within the OpenNESS case studies***

Biophysical modelling	State and Transition Models (STMs)	Models that focus on alternate ecological states and transitions between them. They are useful for understanding ecological functions underpinning ES provision.
	Ecological models	Models that focus on aspects of the biophysical system. Models can come in many forms including both statistical and process-based models.
	Hydrological models	
	Climate envelope modelling	Models that combine information on species' current environmental (e.g. soil, climate) preferences with future environmental data to project potential future climate space for those species.
	Land-use modelling	Models that focus on how land-use changes as a result of changing climatic / socio-economic factors.
mapping - modellin	Integrated mapping-modelling approaches	Any of a range of ecosystem service methods that combine mapping with process-based or statistical modelling e.g. ESTIMAP, InVEST, ARIES etc. Could also include simple GIS techniques that combine statistical approaches to map ES.
Land-use scoring	Matrix approach (land-use only)	Uses land-use as a proxy for ES supply and/or demand using a look up table of ES values (e.g. Burkhard et al., 2012)
	Matrix approach (multiple datasets)	Builds on the land-use only matrix by adding additional datasets plus/minus local knowledge (e.g. Kopperoinen et al, 2014)
Participatory/ deliberative mapping		Approaches where the map making process is used as part of a participatory or discursive process to capture stakeholders understanding of the extent and spatial pattern ES and/or to stimulate discussion on the topic. Includes approaches such as (public) participatory GIS ((P)PGIS) .
Socio-cultural methods	Deliberative valuation	Approaches that aim to assess the value of ES to individuals and groups through open discussion with others (e.g. workshops).
	Narrative analysis	Analysis of people's expressions of interest in ES either verbally or visually (e.g. through interviews, through textual analysis, through interpretation of art or photography).
	Photo-elicitation surveys	Photographs of the landscape are used to capture and understand explore stakeholders' experiences with the ecosystem services they provide.
	Preference assessment	Approaches where individuals' preferences with respect to ES are collected through consultation without using economic analysis. Examples could involve questionnaires, free listing or ranking exercises.
	Time use	Analysis of ES in a similar way to the monetary stated preference approach but focussed on willingness to spend time rather than willingness to pay.
	Scenario development	Creation of storylines of "plausible futures" usually developed within a stakeholder process. The creation of the scenarios often facilitates stakeholders discuss ion and particular scenario elements (e.g. socio-economic changes) can be described or quantified to provide inputs into other methods (e.g. biophysical modelling).
	Photo-series analysis	Approach where geo-located photos uploaded on social media are used as a proxy for revealed ES preferences.
Monetary methods	Stated preference	Broad class of methods where stakeholders are asked how much they would pay to access/ protect etc. a given ES.
	Revealed preference	Broad class of methods that allow ecosystem services access to be judged through the course of action an individual has taken (as opposed to what they state they would do). Includes methods such as hedonic pricing (using house prices) and methods based on travel costs.
	Benefit-cost analysis	Approach that looks at the relationship between the cost of a decision and the benefits that would be accrued.
	Cost-based	A broad class covering market/exchange based methods that use the prices (such as that of an action to minimise/ replace/ restore/ avoid damages) that can then be attributed to an ES providing a similar function.
	Value transfer	Where values quantified in other studies (e.g. published literature) are used to value ES in a different context.
Integrative approaches	Bayesian Belief Networks (BBN)	BBNs use conditional probabilities to describe a (socio-) ecological system as a graphical network of linked nodes. Both qualitative and quantitative data can be added to the network making it a useful tool for integrating different datasets.
	Multi-Criteria Decision Analysis (MCDA)	MCDA is a broad term used to aid decisions by weighting the value given to different alternatives. The alternatives considered are often outputs of other methods allowing MCDA to play a decision support role.

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1169 ***Table SM3: Full method selection considerations addressed within the questionnaire Q2.***

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

1170 ***Table SM4 Examples of how and why methods were combined across the 24 OpenNESS case studies, based***
1171 ***on mind-maps, questionnaires and supplementary ad-hoc interviews with individual case study teams***

Case Study	Input-output	Learning	Individuals	Context transfer	Evolution/ Development	Hybrid approach	Comparison
Barcelona	Incorporation of data held by local stakeholders encouraged the acceptance of the ES approach	Initially market based valuations were considered but methods changed as stakeholders didn't like the monetary approach.	ESTIMAP expert	Transfer of ESTIMAP from European scale to a city scale			
Belgium - De Cirkel	ES mapping used as inputs to PGIS	Card game confirmed relevance of ES to stakeholders which encouraged further engagement with the ES concept	Importance of building relationships with stakeholders who encourage discourage the use of methods	Stakeholder demand analsis from overview context to orchards	Developed own method for benefit/burden analysis		Separate methods focussed on ES demand and on ES supply were used and compared
Belgium - Stevoort		Process led to an evolution of understanding between physical and social scientists	Participatory processes are dependent on the stakeholders present				Comparison of results from multiple mixed-methods was often very meaningful as part of a learning process. Also useful to identify mismatches with expectations to focus more research and build understanding.
Brazil	Stakeholder perceptions of ES supply and demand used as input to discussions	Stakeholder learning developed through the range of methods applied					

Case Study	Input-output	Learning	Individuals	Context transfer	Evolution/ Development	Hybrid approach	Comparison
Cairngorms		Workshop on ES Cascade model used to expose stakeholders to the concept of ES before PGIS workshop.	Engagement with external advisors on ESTIMAP and Monetary methods led to these approaches being used.	ESTIMAP expertise transferred between OPENNESS cases. ESTIMAP experience in study area applied at different scales.	Method assessmnent surveys were used to modify approaches taken. ESTIMAP downscaled to a scale appropriate to the questions of the study areas	Time use method hybridised with PGIS approaches to produce maps of land value	Photoseries and ESTIMAP approaches were both used to assess cultural ES
Carpathians	Participatory mapping and photoseries analysis were used as inputs to monetary valuation of ES	The overall approach developed through learning with individual methods.	OPENNESS partners brought skills with STMs, BBNs and Photoseries analysis	Photoseries, BBN and STM experience transferred from other cases	The overall approach developed through learning with individual methods.		Photoseries outputs compared with those from other cases
Donana	Participatory scenario planning used as inputs to the deliberative mapping process. Social and monetary values used as inputs to integrated valuation approach	each method highlighted aspects of the case not currently considered. Led to focus on different types of value.	Experts from this case influenced research in Warwickshire and Essex		Approach progressively built in different types of value, initially focussing on monetary then socio-cultural and finally biophysical values	No hybrid method mentioned but use integrative approach to bring different values together	Economic validation approaches
Essex		PGIS: Warwickshire -> Essex learning (focus on CES); evolution from workshop-citizen science based.	Research driven by same individuals in warwickshire and essex	Learning and experience with tools transferred from Warwickshire to Essex	Essex approaches modified from those used in Warwickshire		Photoseries outputs compared with recreation and habitat maps from PGIS
Finland	YASSO modelling used as inputs to MCDA.	MCDA approach used to facilitate learning between experts in differnet methods within the research organisation.	Participatory BBN approach taken as a result of taking part in OPENNESS project	Research driven by enthusiasm to transfer ideas from different research contexts within the same organisation	Methods used all developed from existing expertise within the research organisation or the OPENNESS consortium.	Participatory BBN development combining the advantages of a BBN with stakeholder-based socio-cultural approaches	Cross-check between quantitative and qualitative expert assessments and interview analysis

Case Study	Input-output	Learning	Individuals	Context transfer	Evolution/ Development	Hybrid approach	Comparison
France	Scenarios of land-use change used as inputs to DYNAMICA model	Participatory workshops used to determine priority list of services and agreed future scenarios of land-use change	Researchers involved in this case study also heavily involved in S. American studies brought photoseries method to European cases	Photoseries method transferred from Patagonian case study	Development of the BBN spatial was a development of the approach	Developed a spatial BBN to combine the ability to explore trade-offs from the BBN with GIS tools that allowed forest managers to explore spatial implications and trade-offs.	GIS data on biophysical characteristics compared with outcomes from photoseries analysis
Germany	Scenarios provide inputs to the integrated assessment exercise	Experience with modelling approach revealed the need for cultural ecosystem service assessment			Traditional paper based data collection methods evolved into a smart phone app to collect the same data		
Helsinki		Participatory process at core of case study. Individuals learn throughout.	ESTIMAP Expert brough skills and experience with model. Links to other sites using ESTIMAP.	Invited the ESTIMAP expert to the case study to test the method in a new case and to increase the number of ES considered	ESTIMAP was developed to address new ES within the case		ESTIMAP and PGIS outputs were overlaid with current outputs and the plan in a participatory process
Hungary	Used a series of workshops in which the data from one fed into the next. GIS used to take in primary data, water availability and soil fertility data into a single spatial model.	Methods used in workshops built learning between stakeholders and scientists	Experts wit h Quickscan and ESTIMAP led to their application within the case	Transfer of method experience from other contexts (Quickscan and ESTIMAP)	Drawing competition methodology developed as a means to access young people's views	No mention of tool hybridisation	Comparison of different stakeholder values as highlighted by different methods

Case Study	Input-output	Learning	Individuals	Context transfer	Evolution/ Development	Hybrid approach	Comparison
India		Participatory approaches build understanding of ES	Proactive leaders enabled methods to be trialled and combined	Participatory monitoring approaches were compared between 10 different contexts	Developed an approach of collaborative participatory monitoring that combined traditional field work with participatory approaches to build collaborations between the community and forest department	Participatory monitoring combined field-based nature of traditional field work with participant approaches to develop cohesion.	No. The same methods were trialled and compared accross differnet locations
Italy	Fieldwork, hydrology models and questionnaire data all used as inputs to MCA	increasing learning of overall issue supported by method combinations	Two economists in the team supported the selection of monetary methods. BBN interest from OPENNESS partner	Site partners chose MCA as they had previous experience of it in other contexts			
Kenya	Field surveys as input to ES assessments	Stakeholder workshops used before all other methods to bring all participants to similar level of understanding of terminology and concepts	OPENNESS ESTIMAP expert brought skills to case	ESTIMAP expertise from Europe extrapolated to African case			Pollination mapping from ESTIMAP with field survey experience and photoseries data
Loch Leven	Statistical analysis of angling data used as an input to the BBN analysis. Photoseries used to get weights for ESTIMAP model	Consultation with stakeholders used to inform BBN design	External expertise supported ESTIMAP, Photoseries and BBN application		Photoseries analysis of recreational opportunities developed into conflict analysis between birds and tourism		Comparison of bird locations from photoseries with existing data on bird habitats to identify conflicts between bird breeding and recreation. ESTIMAP and photoseries methods combined to provide different information on recreational ES.

Case Study	Input-output	Learning	Individuals	Context transfer	Evolution/ Development	Hybrid approach	Comparison
Oslo	PGIS data on people's favourite walking routes used as input to ESTIMAP's recreation assessment	Learning which monetary and non-monetary methods worked where	ESTIMAP Expert brought skills to map recreation and brought an opportunity to focus on pollination using ESTIMAP also.	Hedonic pricing method outputs from one case study (O1) were used as property prices through value transfer in a second case (O2)	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	Contingent willingness to pay and PGIS favourite path mapping combined in a web survey that combined the two methods	outputs from a BBN valuation of trees was compared with contingent WTP for city trees
Patagonia	Historical data and data from previous studies used as inputs to the BBN	Stakeholder workshops used to build understanding of the modelling process	Argentinian Researcher from Norwegian research institute and Patagonian team both interested in the use of STMs in an ES context and how decisions can be made using them with a BBN	Experience with STMs but not in an ES context	Needed to develop their own methods as many of the methods available were customised for other contexts or areas with greater existing data	Biophysical model co-produced with stakeholders by developing an STM within a deliberative workshop	
Portugal		Photo elicitation used to target ES for analysis in subsequent stages. Methods combined in an iterative and sequential process, learning from one fed into the next.	Stakeholders are key links between methods, different stakeholders would lead to different results	Learning on what methods worked in what context transferred between contexts			Results of the different methods were compared: e.g. between participatory mapping, expert/GIS methods and ESTIMAP.
Romania	Photoseries analysis used as cultural ecosystem service inputs to MCDA	Learning from the spreadsheet approach encourages the need for stakeholder engagement	External expertise supported Quickscan application in the case and Spreadsheet use	via individuals	Spreadsheet matrix approach as a quick approach then followed by Quickscan		

Case Study	Input-output	Learning	Individuals	Context transfer	Evolution/ Development	Hybrid approach	Comparison
Sierra Nevada	Preference assessments and biophysical indicators of water quality assessment fed into choice experiments	The methods required changed with stakeholder questions which developed as they learnt through the process	Key individuals that came into the process at various stages (e.gg. PhD Students) guided the methods selected and applied	Experiences with PGIS methods transferred from this case to Warwickshire case	It became clear that using language as a communicatio n tool wasn't getting access to people's views and values and so picture-based methods were explored to access these	Not mentioned	InVEST and PGIS compared as part of Local Ecological Knowledge assessment
Slovakia	The enhanced land-use scoring ("Greenframe") approach provided some inputs to the Quickscan process	Better understanding of stakeholder needs develop following application of basic land-use scoring approach. Recognise a need for greater robustness.	Case study researchers inspired by experiences from the Finnish case	ESTIMAP method experience transferred from other cases	Initially used simple land-use scoring approach but needed information on quality of the environment not just structure and is more scientifically sound	Quickscan/BBN combination developed to target urban green space	ESTIMAP and the simple spreadsheet method were both used to assess recreation.
Warwickshire		Experience applying PGIS tools in Warwickshire led to the tool being applied differently in Essex (to focus on CES)	researcher from Donana/Sierra Nevada case study brought skills and experience with PGIS/Photoseri es from case study	Methods used in this case were transferred to Essex case with some modification	simple matrix approach was combined with a participant workshop for local context	Combined methods for expert based assessment of ES with matrix-based approach to ensure the latter reflected local concerns	Photoseries outputs compared with recreation and habitat maps from PGIS

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