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## 1 Integrating methods for ecosystem service assessment: experiences from real 2 world situations

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## 70 **Abstract**

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

86

## 87 **1 Introduction**

88 The popularisation of the Ecosystem Services (ES) concept has led to a significant uptake of  
89 ecosystem service based approaches in national and international policy frameworks (TEEB,  
90 2010; Bateman et al., 2014; UN et al., 2014; IPBES, 2015, Maes et al., 2016). This, along with  
91 increased awareness of the interconnectedness of the natural environment and the  
92 widespread contributions of the natural world to human wellbeing, has put increasing  
93 pressure on practitioners in the land-use and environment sectors to assess and manage  
94 natural capital in a way that better reflects these holistic benefits.

95

96 This poses significant challenges. As the Ecosystem Service concept has become more  
97 widely recognised, so the number of tools/methods (treated here as synonyms) available to  
98 assess ES has increased (Harrison et al., 2017; Bagstad et al., 2013). Individual ecosystem  
99 service tools, however, are often insufficient to meet the varied needs of land management  
100 challenges, and practitioners will therefore need to find the right combinations of tools to  
101 meet their needs – and to enable them to assess the broad range of values provided by  
102 nature (Jacobs et al., 2017). Whilst there are a number of studies that attempt to provide  
103 guidance on which tools to use under which circumstances (e.g. Vatn, 2009; Bagstad et al.,  
104 2013; Martinez-Harms et al., 2015; Ruckelshaus et al., 2015; Hirons et al., 2016; Grêt-  
105 Regamey et al., 2016), there has to date been no study that takes a bottom-up, example-  
106 based look at the range of tools required to address real-world case studies and the  
107 practical factors that drive the selection and combination of different methods.

108

109 The OpenNESS project (EU FP7; 2012-2017, [www.openness-project.eu](http://www.openness-project.eu)) investigates the  
110 factors that influence the extent to which the Ecosystem Service concept can be put into  
111 practice in 24 real-world case studies, predominantly in Europe, but also in India, Kenya,  
112 Argentina and Brazil (see Table SM1 and Wijna et al., 2016 for further information). These  
113 case studies provide a test bed for assessing the utility of ecosystem service tools in  
114 practice, and the way in which different tools can be combined to address real-life  
115 problems. Within this paper we address three research questions:

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

120 We aim to provide grounded insights and examples to assist others embarking on  
121 ecosystem service assessments where priorities are driven by practical end-user needs.  
122

## 123 **2 Methodological approach**

124 The OpenNESS case-studies address a range of ecosystem management/planning challenges  
125 that were selected by practitioners (Table SM1). In each case study a *research team*, funded  
126 by the project, worked alongside a team of local *stakeholders* who are involved with the  
127 management of and/or have some interest and/or dependency on the case study's central  
128 issue. Case study teams were able to choose one or more tools to meet their needs, with  
129 training being provided. This paper is based on the research teams' explanations of the  
130 factors that influenced their selection and combination of tools to meet the stakeholders'  
131 needs.  
132

133 The methods available for selection by the case study teams are listed in full in Table SM2.  
134 There are many ways to group methods but within this paper we group them into seven  
135 classes according to the type of ES values assessed: biophysical, socio-cultural or monetary  
136 (Gomez-Baggethun et al., 2015), as shown in Figure 1. The classification also reflects the  
137 level of stakeholder participation, the level of biophysical realism reflected within the model  
138 (following Lavorel et al., 2017) and which parts of the ES cascade the method focusses on  
139 (biophysical structures and functions, ecosystem services or benefit and values to humans;  
140 Haines Young and Potschin, 2010). The main classes of model are summarised below.  
141

142 *Biophysical models*: these process-based models assess biophysical value using a higher  
143 level of biophysical realism than approaches based on land-use proxies. They are based on  
144 detailed quantitative understanding of biophysical relationships within the environment and  
145 tend to focus on the structure/function part of the ES cascade. It is rare, but possible, to  
146 include stakeholder participation within the modelling.  
147

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

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

152

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

159

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

165

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

173

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

178

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

Overarching method class	Name	Values			Involves stakeholders	Biophysical model type	Cascade				
		Biophysical	Socio-cultural	Monetary			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		○	○	●

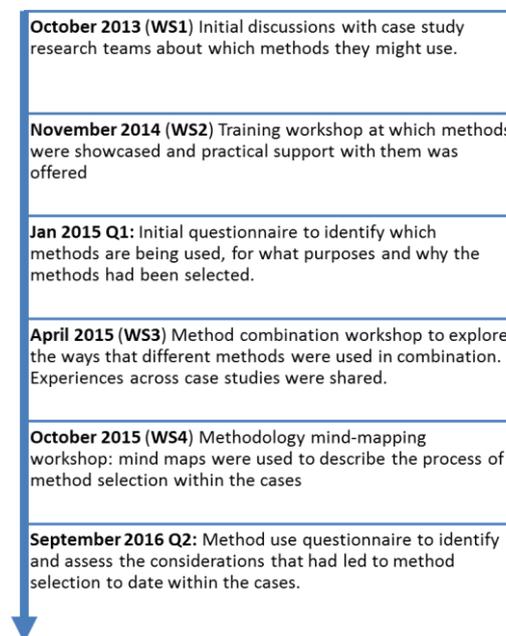
186  
187 **Figure 1 Overview of broad classes of methods used within this study. Values/Cascade: ● primary priority**  
188 **○ secondary priority ○ lower priority; blank = not addressed. “Involves stakeholders” colours reflect the**  
189 **text. Biophysical model types (following Lavorel et al., 2017) reflect level of biophysical realism from those**  
190 **that use land-use as a simple proxy (↓), through phenomenological models that include additional**  
191 **understanding of the biological mechanisms (→, ↗) through to more advanced methods including niche- and**  
192 **trait-based approaches and process models of the biophysical system (↑).**

193  
194 Data on tool use was collected through a series of questionnaires and workshops with the  
195 24 case study research teams (Figure 2). Initial surveys (Q1) encouraged research teams to  
196 express in their own words the reasons for the selection of individual tools. This data was  
197 interpreted and coded into themes that reflected the major factors taken into consideration  
198 when methods were selected (Table SM3). These factors, referred to as “considerations”  
199 within this paper, covered a broad range of issues under six main themes:

- 200 1) the types of **ecosystem service** that were the focus of the case study;  
201 2) the **management or policy context** of their study: e.g. were they interested in  
202 exploring ideas, providing information, making decisions or designing policy  
203 instruments; for more information see Barton et al., (this issue);  
204 3) a range of **pragmatic constraints** that might have influenced their choice of  
205 methods: such as budget, time and expertise;  
206 4) considerations related to the **research process**, such as whether the technique was  
207 novel, transferable and produced scientifically robust results;

- 208 5) particular **methodological considerations**, such as a method's ability to involve  
209 stakeholders, provide spatially explicit outputs or address uncertainty;  
210 6) and factors related to the **stakeholder-driven** nature of the OpenNESS research,  
211 such as whether the method selection was driven by the end-users themselves.  
212

213 A further survey (Q2) was circulated after completion of the case studies, in which the  
214 research teams were asked to score the extent to which each of the considerations  
215 influenced their decision to use each method (0 = not at all; 1 = to some extent; 2 =  
216 definitely). They were also asked to assess, in free text: i) their reasons for combining  
217 methods; ii) whether the combination of methods they used met their aims; iii) any  
218 problems and challenges resulting from combining methods and iv) their views on the  
219 impact of method combination on the scientific robustness of the results (Table SM4).  
220



221  
222 **Figure 2 Timeline providing an overview of workshops (WS1-4) and questionnaires (Q1&2) focussed on**  
223 **method combinations.**

224  
225 In addition to survey data, workshops were used to ascertain how the case studies were  
226 using methods to meet their specific goals (WS1-4) and to understand how methods were  
227 being combined (WS 3-4). The final workshop (WS4) produced participatory mind maps  
228 detailing the methods used, the ways in which methods are combined and the  
229 considerations that influenced method selection and combination.

230  
231 The questionnaires and mind maps were thematically analysed across all case studies to  
232 identify common factors influencing selection of individual methods and the way in which  
233 methods were combined. Where necessary, ad hoc interviews with the case study research  
234 teams were used to fill in additional details and clarify uncertainties.

235

### 236 3 Results

#### 237 3.1 What methods were combined within the OpenNESS case studies?

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

242  
 243 The number of methods combined varies widely: most case studies (75%) combined at least  
 244 four methods and 42% combined six or more, with one (Oslo) combining 15. Socio-cultural  
 245 and participatory mapping methods were the most commonly used method classes (used in  
 246 83% and 67% of studies respectively), with all but two studies using at least one of these  
 247 methods. Integrated mapping-modelling approaches and biophysical modelling were used  
 248 less often (46% and 38% respectively) and land-use scoring approaches were only used in  
 249 25% of cases, but all but five cases used at least one of these methods. Monetary methods  
 250 were only used in a third of case studies. Just under half of case studies used either MCDA  
 251 or BBNs as an integrative method, with two combining both of these methods.

252

	Biophysical		Int. Mapping-Modelling		LU scoring		Participatory Mapping		Non-monetary					Monetary			Integrative		Count (methods in case study) ->									
	State and Transition Models (STMs)	Land use modelling	Ecological models	Hydrological models	ESTIMAP	INVEST	Integrated mapping-modelling (other)	Approach based on land use data only	Approach based on multiple datasets	QuickScan	PGIS	Participatory Mapping (other)	Preference assessment	Photo-series analysis	Narrative analysis	Time use	Deliberative valuation	Photo-elicitation surveys		Scenario development	Cost-based	Value transfer	Stated preference	Revealed preference	Benefit-cost analysis	Criteria Decision Analysis (MCDA)	Bayesian Belief Networks (BBN)	
Method count-->	2	2	2	1	2	10	2	3	5	2	8	4	7	12	10	6	3	7	3	6	6	3	6	1	1	5	8	
Oslo	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	15
Donana	●										●	●							●							●		10
Romania								●			●	●														●	●	9
Hungary					●		●				●	●																8
Sierra Nevada						●	●				●	●																8
Cairngorms						●					●	●														●		6
Carpathians	●	●									●	●														●		6
Patagonia	●	●									●	●														●		6
Portugal					●	●					●	●																6
Slovakia					●						●	●																6
Kenya					●							●														●		5
Barcelona					●							●														●		4
Belgium - De Cirkel											●	●														●		4
Essex			●				●				●	●																4
Germany	●										●	●																4
Italy				●								●														●		4
Loch Leven					●						●	●														●		4
Warwickshire			●								●	●																4
Brazil												●														●		3
France												●														●		3
Belgium - Stevoort											●	●																2
Finland												●														●	●	2
Helsinki							●				●	●																2
India			●								●	●																2

253

254 *Figure 3: Overview of method usage within the 24 case studies; white circles indicate a single method; black*  
255 *circles indicate more than one method of the same type. Colours reflect overarching method classes; the*  
256 *coloured bars on the left indicate presence or absence of at least one method of each class.*  
257

### 258 **3.2 What factors drive the need for method combination?**

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

262

263 a) a need to assess **a range of different ES** beyond those possible with a single  
264 method;

265 b) a need to assess **different elements of the ES cascade**, i.e. to look at both supply  
266 and demand, or at different elements of ecosystem structures, functions,  
267 services, benefits or values;

268 c) a need to assess **different aspects of value** (biophysical, socio-cultural,  
269 monetary) within a case study;

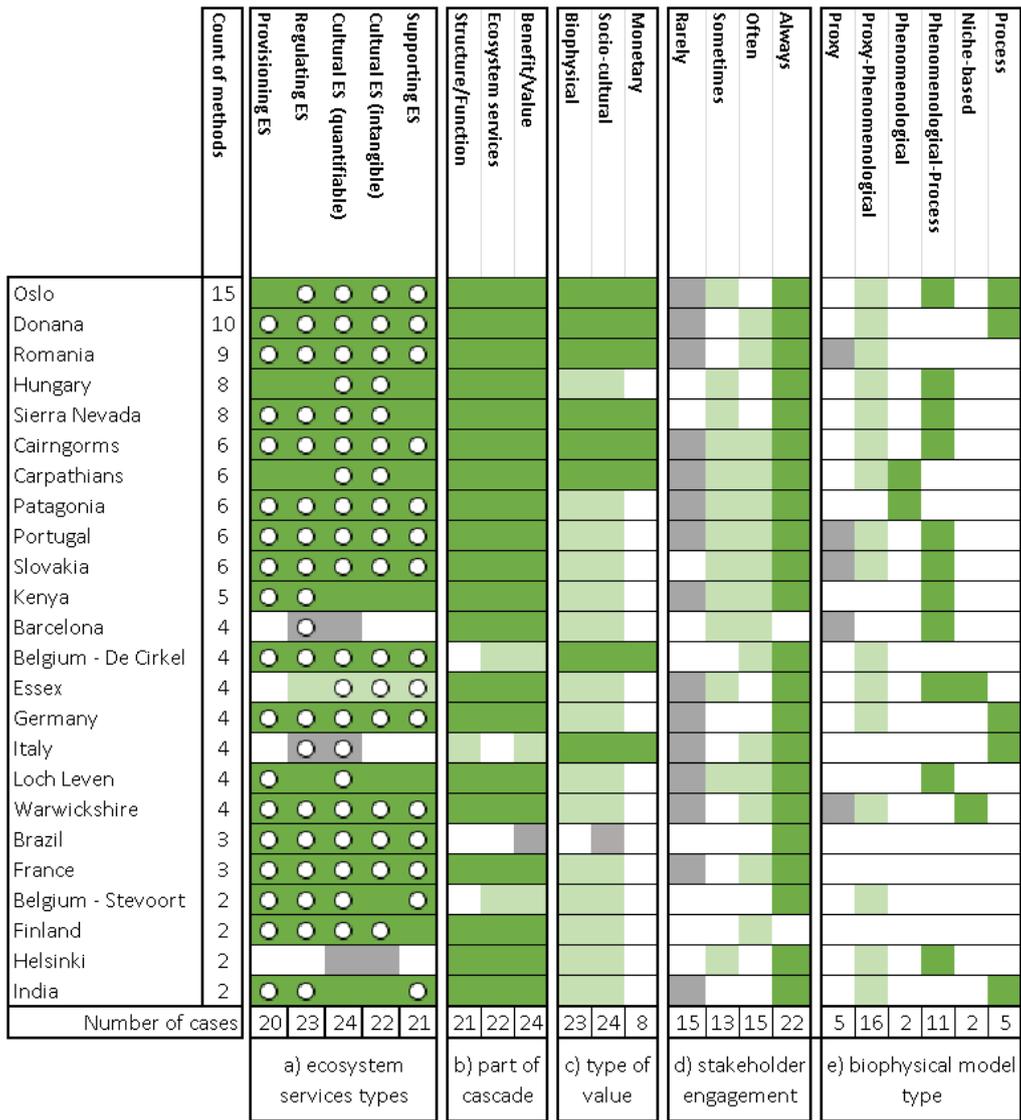
270 d) a need to **engage with different types of stakeholder**;

271 e) a need to **address methodological concerns** relating to the use of a single  
272 method (e.g. to increase robustness, for validation);

273 f) selecting methods to address **different stages of the research/case study's**  
274 **development.**

275

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



282  
 283  
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 286

**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).**



291

### 292 **3.2.1 Selecting methods to address a range of different ES within a case study**

293 *Why is this important?*

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

299

300 *How was it addressed in the OpenNESS case studies?*

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

307

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

316

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

322

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

327

### 328 **3.2.2 Selecting methods to address different elements of the ES cascade**

329 *Why is this important?*

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

336

337 *How was it addressed in the OpenNESS case studies?*

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

342

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

353

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

362

### 363 **3.2.3 Selecting methods to assess different aspects of value for ES**

364 *Why is this important?*

365 There are many ways of classifying value (see IPBES, 2015) but here we focus on the three  
366 traditional classes of value: biophysical, socio-cultural and monetary (Gomez-Baggethun et  
367 al., 2016). The differences in how a problem can be understood through monetary units  
368 (e.g. price/ha timber), biophysical units (MtCO<sub>2</sub>e of carbon storage) and socio-cultural  
369 values (“I love forests”) exemplify the challenge of assessing the value of ecosystem services  
370 to human wellbeing. There was great interest within many of the case studies in ensuring

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

376

377 *How was it addressed in the OpenNESS case studies?*

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

### 390 **3.2.4 Selecting methods to reach different stakeholder groups**

391 *Why is this important?*

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

400

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

410

411 *How was it addressed in the OpenNESS case studies?*

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

418

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

428

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

436

### 437 **3.2.5 Combining methods to address concerns with using a single method**

438 *Why is this important?*

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

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

453

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

470

471 *How was it addressed in the OpenNESS case studies?*

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

482

### 483 **3.2.6 Combining methods to address different stages of the research/case study's** 484 **development (decision contexts)**

485 *Why is this important?*

486 Within practical case studies different methods are needed at different stages of the  
487 “decision context”, e.g. awareness raising, problem formulation, target setting and decision-  
488 making. This is important as the decision context determines the extent to which a  
489 combination of methods is seen as a “success” in the eyes of practitioners (see McIntosh et  
490 al., 2011; Dick et al., this issue). A number of decision contexts highlighted by the  
491 stakeholder assessments are discussed below including those related to i) spatial scale; ii)  
492 temporal scale; iii) awareness raising; iv) project evaluation and conflict resolution; v)  
493 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  $\geq 55\%$  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

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

541

542 Many of the case studies used an integrative method to draw together the results of the  
543 other methods applied in the case study. Also, many of the case-studies will have used  
544 reports (e.g. Reinvang et al., 2014; Barton et al., 2015) or presentations, meetings or  
545 workshops with end users (e.g. Kenya, Portugal): these processes are integrative methods in  
546 themselves.

547

### 548 **3.2.7 Additional factors driving method selection**

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

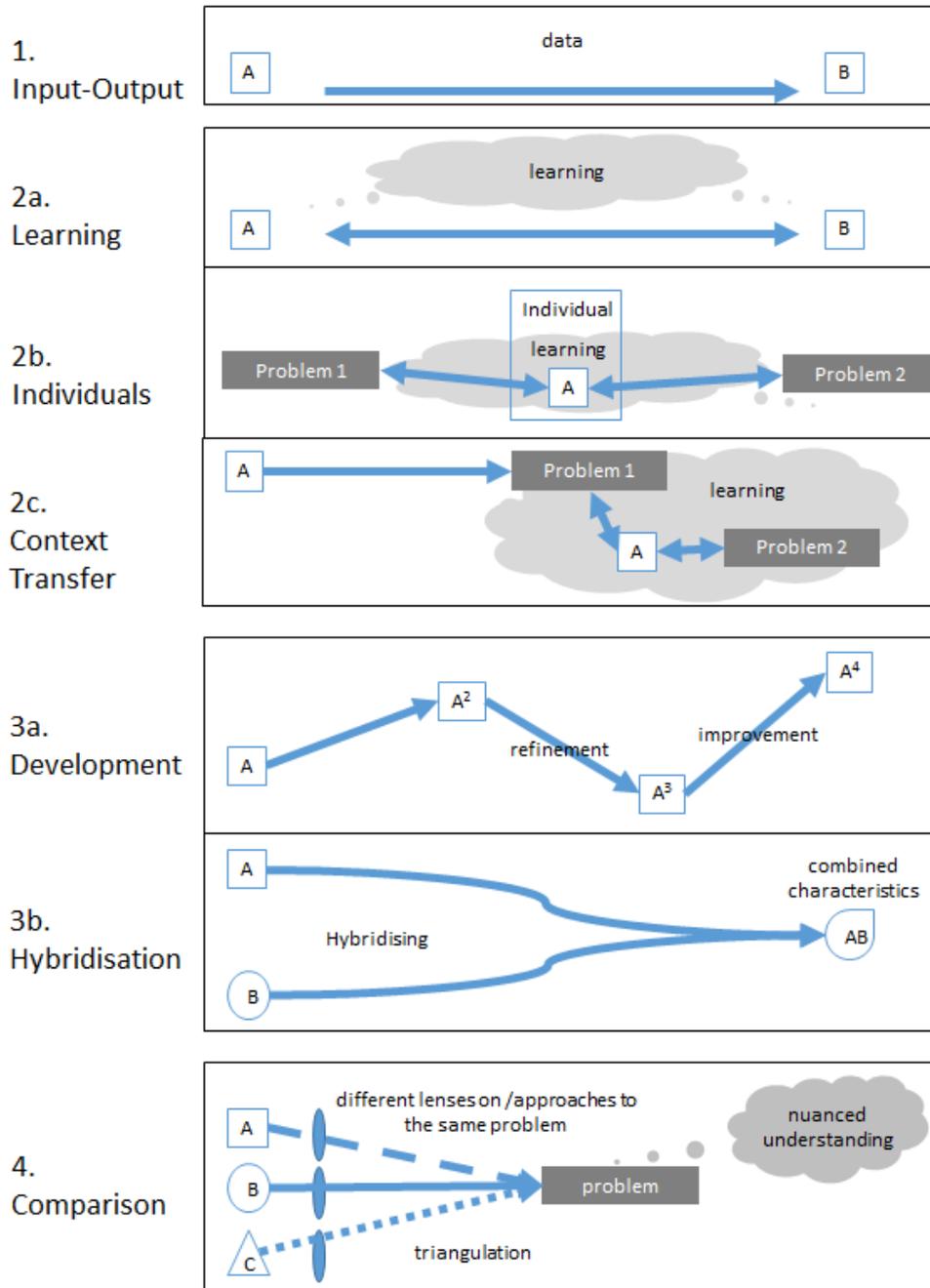
554

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

### 572 **3.3 How are methods combined within practical cases?**

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

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



579

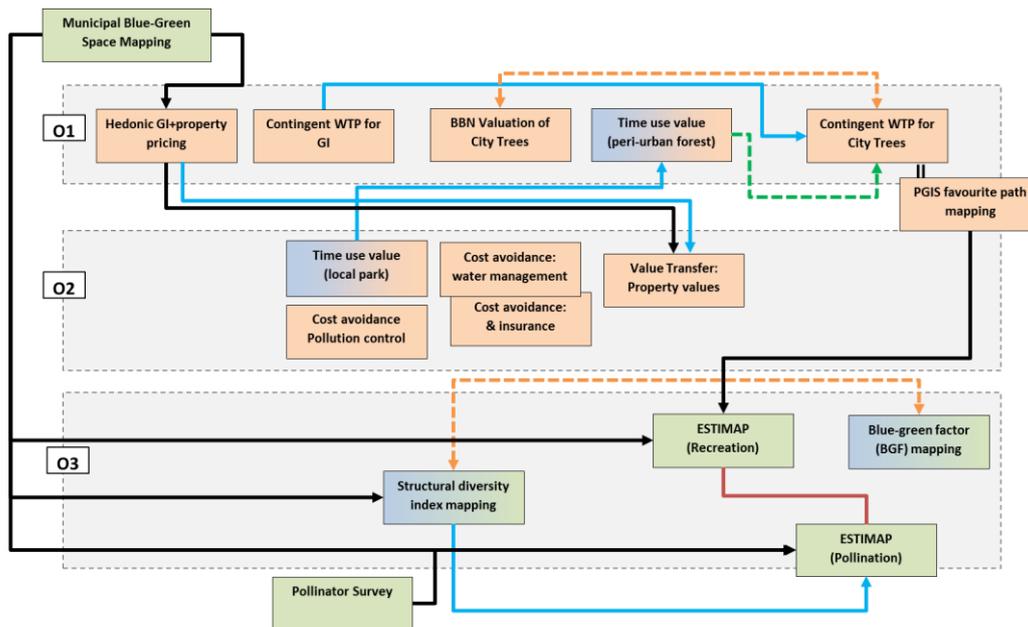
580 **Figure 6: Linkage between methods identified within the OpenNESS case studies**

581

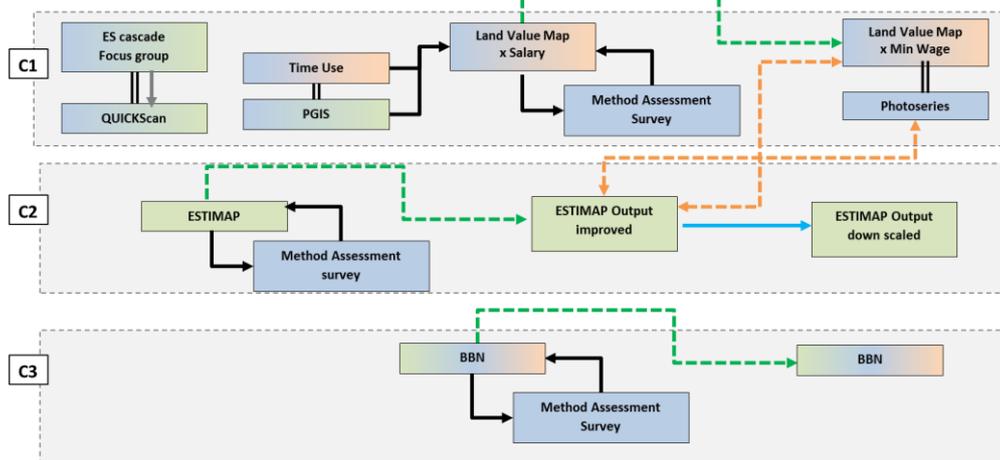
582 Figure 6 illustrates the concepts behind the types of linkage. In the sections below we draw  
 583 on experiences from across all 24 case studies (Table SM4) that demonstrate these different  
 584 types of linkage, with particular reference to two examples: Oslo and the Cairngorms. Figure  
 585 7 provides a diagrammatic representation of how methods were linked within these two  
 586 case studies to address their aims.

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588  
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594

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

595  
596  
597  
598

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

### 599 3.3.1 Input-output transfers of data

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

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

610

611 Inputs may also come from methods outside the case study research, e.g. from existing  
612 datasets or prior research, including value transfer from other studies. In Oslo, for example,  
613 municipal blue-green space mapping by the Agency of Urban Environment forms an input to  
614 methods in both O1 and O3 (Figure 7). This incorporation of existing knowledge/data can be  
615 crucial and has also been shown to increase the acceptance of the ES approach by local  
616 stakeholders (e.g. Barcelona).

### 617 **3.3.2 Links through learning**

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

631

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

684 was used to enable the research team and local experts to co-design and co-produce a  
685 biophysical State and Transition Model (STM) model that could be used to evaluate forest  
686 change. In these instances, combining methodologies helps to overcome weaknesses in the  
687 individual approaches, e.g. maximising inclusion of local ecological knowledge/specialist  
688 expertise whilst producing spatial outputs/biophysical models. In another example, a case  
689 study in the French Alps combined GIS tools with a BBN model of trade-off opportunities to  
690 produce a hybrid spatial BBN. This allowed forest managers to evaluate the spatial  
691 implications and trade-offs between forest production and conservation measures to  
692 preserve biodiversity in forested habitats (Gonzalez-Redin et al., 2016).

693

694 In other examples, methods evolved in an iterative manner as a response to feedback,  
695 learning or changes in circumstance within a case study. In the Cairngorms (C1), the hybrid  
696 time use/PGIS method was improved through the use of socio-cultural methods (a  
697 stakeholder survey) to assess stakeholder concerns with the method. In response, the  
698 monetisation approach was modified from an approach based on participant salary, to one  
699 based on the minimum wage as this was thought to be a fairer reflection of value. Similarly,  
700 learning between case studies can lead to the evolution of methods. PGIS approaches  
701 trialled in Warwickshire were modified when the method was transferred to Essex, based  
702 on case study learning that suggested that, in the local context, the approach used provided  
703 better responses when focussed on cultural ecosystem services (rather than provisioning/  
704 regulating services).

705

706 In other cases innovative new methods were developed to address aspects particularly  
707 important to the case studies. For example, in Hungary it was seen to be very important to  
708 include the values of future generations in ecosystem service assessments and a new  
709 “drawing competition” methodology was developed to ensure “young people get to have a  
710 voice”. In the method young children were asked to contribute pictures related to their  
711 perceptions of the value of nature and their views of the future. These were included along  
712 with spatial modelling, statistical approaches and participatory mapping outputs in a final  
713 workshop that led to policy recommendations.

714

715 Finally, in some cases new methods had to be developed because existing methods were  
716 not available or context-appropriate. In Patagonia, where there was limited available data  
717 on cultural services and many of the methods proposed within OpenNESS were unsuitable  
718 because they were customised for Europe, the case study developed the photoseries  
719 approach to map and quantify cultural services.

720

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

724

### 725 **3.3.4 Method comparison**

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

732

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

743

## 744 **4 Discussion**

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

750

### 751 **4.1 Challenges and opportunities in combining methods**

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

#### 755 **4.1.1 Pragmatic concerns**

##### 756 *Challenges faced*

757 Practical constraints on time, cost, data availability and technical expertise (see section  
758 3.2.7) led to challenges for case study teams combining multiple methods: challenges that  
759 increase with the technical complexity of the methods combined. Time demands may also  
760 increase as case studies adapt and evolve due to changing understanding of the issue at  
761 hand and/or changing stakeholder interests.

762

##### 763 *Successes and opportunities*

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

#### 772 **4.1.2 Stakeholder-related**

##### 773 *Challenges faced*

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

782

##### 783 *Successes and opportunities*

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

#### 794 **4.1.3 Scientific robustness and reproducibility**

##### 795 *Challenges faced*

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

804 community (e.g. Flickr users). Scenario methodologies make assumptions based on how the  
805 future will evolve. It is important to recognise that combining multiple methods may lead to  
806 aggregation of these uncertainties, especially for methods combined in an input-output link  
807 (3.3.1) or transferred across contexts (3.3.6).

808

#### 809 *Successes and opportunities*

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

818

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

829

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

840

#### 841 **4.1.4 Combining disparate methods**

##### 842 *Challenges faced*

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

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

848

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

861

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

869

#### 870 *Successes and opportunities*

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

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

#### 890 **4.1.5 Scale**

##### 891 *Challenges faced*

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

903

##### 904 *Successes and opportunities*

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

921

#### 922 **4.2 Take-home messages**

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

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

#### 927 **4.2.1 Why use combinations of methods in ecosystem service assessments?**

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

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

#### 956 **4.2.2 What methods should be combined?**

957 There is no one-size-fits-all solution to ecosystem services assessment, and it is beyond the  
958 scope of this paper to provide definitive guidance on which tools to combine, as this will  
959 depend on the case study context. However, it is clear that researchers should plan to build  
960 in a range of techniques to cover different aspects of the issue in question. Based on the  
961 experience of the OpenNESS case studies, a general recommendation would be:

962 **Step 1) Set-up.** Identify a representative stakeholder group; convene an advisory  
963 board to ensure robustness; and assess user needs. This will require socio-cultural  
964 techniques (surveys, workshops, interviews, etc.) and there are a number of tools

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

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

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

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

## 986 **5 Conclusion**

987 This paper has demonstrated the range and variety of methods applied in ecosystem service  
988 assessment in 24 case studies across a wide range of contexts. It has highlighted the ways in  
989 which methods can be combined, and identified the range of considerations addressed  
990 when selecting methods. Combining different methods can greatly strengthen ES  
991 assessments, allowing them to address the full range of relevant ES and value types,  
992 engaging different stakeholder groups, highlighting areas of uncertainty, building a deeper  
993 understanding of the socio-ecological system, and facilitating method development and  
994 learning. However there are a number of challenges to be addressed, including practical  
995 constraints on time, resources and expertise, and the difficulties of interdisciplinary  
996 working. Successful application of combined methods will require a good understanding of  
997 the strengths and weaknesses of individual methods, and maintain a flexible and dynamic  
998 approach that can respond to opportunities and constraints as they arise.  
999

1000 Whilst the complexity of socio-ecological systems and the competing demands for nature's  
1001 goods and services present major challenges for ecosystem management, the case studies  
1002 presented here demonstrate how ecosystem service assessment methods can be combined  
1003 in innovative and creative ways to create customised solutions that address practical user

1004 needs. By sharing and learning from the experiences of stakeholders, practitioners and  
1005 researchers from different disciplines (e.g. via the OPPLA hub), we can ensure that these  
1006 innovative approaches diffuse quickly and enhance our options for sustainably managing  
1007 the services our ecosystems provide.

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1013

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1158 **Supplementary materials**

1159 *Table SM1: Overview of the 24 OPENNESS case studies within this paper (Colours reflect the case study*  
 1160 *groupings). Information on case study “issue” from Wijnja et al., 2016. For further Case Study information*  
 1161 *including more detail on the study area, what was done and achieved within OPENNESS, and lessons learned*  
 1162 *from the cases see Wijnja et al., 2016.*  
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Country	Case Study	
Belgium	De Cirkel	<p><b>Detail on case study and explanation of why method combinations were required.</b></p> <p><b>Reconciling land consolidation and multifunctional agricultural landscapes: Project De Cirkel (Limburg, Belgium)</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>
Belgium	Stevoort	<p><b>Integration of ecosystem services in the planning of a flood control area in Stevoort, Belgium</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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).</p> <p><b>Case Study group: Integrated river basin management</b></p>
Brazil	São Paulo region	<p><b>Biofuel farming and restoration of natural vegetation in the São Paulo region, Brazil</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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).</p> <p><b>Case Study group: Commodity export dominated areas in developing countries</b></p>

England	Warwickshire	<p><b>Tools for investigating biodiversity offsetting in Warwickshire, England</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>
England	Essex	<p><b>Ecosystem service mapping in Essex, England</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> Run in tandem with Warwickshire case by the same research team. Same purpose for method combination</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>
Finland	Helsinki	<p><b>Operationalising ecosystem services in urban land-use planning in Sibbesborg, Helsinki Metropolitan Area, Finland</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> The two methods used, PGIS approach and ESTIMAP analysis complemented each other in the case study research</p> <p><b>Case Study group: Sustainable urban management</b></p>
Finland	Finland	<p><b>Forest bioenergy production in Finland</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Management of forests/woodlands</b></p>

France	French Alps	<p><b>Operationalising ecosystem services in regional and national forest management planning in the multifunctional landscape of the French Alps</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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</p> <p><b>Case Study group: Management of forests/woodlands</b></p>
Germany	Saxony	<p><b>Bioenergy production in Saxony, Germany</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>
Hungary	Kiskunság	<p><b>Supporting sustainable land-use and water management practices in the Kiskunság National Park, Hungary</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>
India	Bankura and Sundarbans	<p><b>Participatory biodiversity management for ecosystem services in Bankura and Sundarbans, India</b></p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Commodity export dominated areas in developing countries</b></p>

Italy	Gorla Maggiore	<p><b>Nature-based solution for water pollution control in Gorla Maggiore, Italy</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> Methods were combined to cover different aspects of the integrated valuation of ecosystem services (biophysical quantification, monetary and non-monetary valuation, MCA)</p> <p><b>Case Study group: Integrated river basin management</b></p>
Kenya	Kakamega	<p><b>Operationalising ecosystem services for improved management of natural resources within the Kakamega Forest, Kenya</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Commodity export dominated areas in developing countries</b></p>
Norway	Oslo	<p><b>Valuation of urban ecosystem services in Oslo, Norway</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Sustainable urban management</b></p>
Patagonia	National	<p><b>Retention forestry to improve biodiversity conservation and ecosystem services</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Commodity export dominated areas in developing countries</b></p>

Portugal	Costa Vicentina	<p><b>Operationalising ecosystem services in the Sudoeste Alentejano e Costa Vicentina Natural Park, Portugal</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Coastal area management</b></p>
Romania	Carpathians	<p><b>Forest management in the Carpathian Mountains, Romania</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Management of forests/woodlands</b></p>
Romania	Romania	<p><b>Operationalising ecosystem services for an adaptive management plan for the Lower Danube River, Romania</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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)</p> <p><b>Case Study group: Integrated river basin management</b></p>

Scotland	Cairngorms	<p><b>Improved, integrated management of the natural resources within the Cairngorms National Park, Scotland</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>
Scotland	Loch Leven	<p><b>Quantifying the consequences of the European water policy for ecosystem service delivery at Loch Leven, Scotland</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> BBN &amp; ESTIMAP methods focused on different services and were not combined. Photo-series was used specifically to get weights for the ESTIMAP model</p> <p><b>Case Study group: Integrated river basin management</b></p>
Slovakia	Trnava	<p><b>Landscape-ecological planning in the urban and peri-urban areas of Trnava, Slovakia</b></p> <p><b>Issue:</b> Trnava 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.</p> <p><b>Why combine methods:</b> 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,</p> <p><b>Case Study group: Sustainable urban management</b></p>
Spain	Sierra Nevada	<p><b>Ecosystem services in the multifunctional landscape of the Sierra Nevada, Spain</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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</p> <p><b>Case Study group: Mixed Rural Landscapes</b></p>

Spain	Doñana	<p><b>Operationalization of ecosystem services in the cultural landscapes of Doñana, south-west Spain</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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 through workshops.</p> <p><b>Case Study group: Coastal area management</b></p>
Spain	Barcelona	<p><b>Mapping ecosystem services to inform landscape planning in the Barcelona metropolitan region, Spain</b></p> <p><b>Issue:</b> 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.</p> <p><b>Why combine methods:</b> 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.</p> <p><b>Case Study group: Sustainable urban management</b></p>

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**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 scoring	Land-use modelling	Models that focus on how land-use changes as a result of changing climatic / socio-economic factors.
	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.
Participatory/ deliberative mapping	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)
Socio-cultural methods	Deliberative valuation	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) .
	Narrative analysis	Approaches that aim to assess the value of ES to individuals and groups through open discussion with others (e.g. workshops).
	Photo-elicitation surveys	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).
	Preference assessment	Photographs of the landscape are used to capture and understand explore stakeholders' experiences with the ecosystem services they provide.
	Time use	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.
	Scenario development	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.
	Photo-series analysis	Creation of storylines of "plausible futures" usually developed within a stakeholder process. The creation of the scenarios often facilitates stakeholders discussion and particular scenario elements (e.g. socio-economic changes) can be described or quantified to provide inputs into other methods (e.g. biophysical modelling).
Monetary methods	Stated preference	Approach where geo-located photos uploaded on social media are used as a proxy for revealed ES preferences.
	Revealed preference	Broad class of methods where stakeholders are asked how much they would pay to access/ protect etc. a given ES.
	Benefit-cost analysis	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.
	Cost-based	Approach that looks at the relationship between the cost of a decision and the benefits that would be accrued.
	Value transfer	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.
Integrative approaches	Bayesian Belief Networks (BBN)	Where values quantified in other studies (e.g. published literature) are used to value ES in a different context.
	Multi-Criteria Decision Analysis (MCDA)	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.
		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.

**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

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**Table SM4 Examples of how and why methods were combined across the 24 OpenNESS case studies, based 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 analysis 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 assessment 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 different 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 brought 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 with 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 across different 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.g. 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 communication 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/Photoseries 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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