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1 **Long Title:** Distilling the role of ecosystem services in the Sustainable Development Goals

2

3 **Short Title:** Ecosystem Services and the SDGs

4

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41 Modelling; Policy Review

42
43
44 **Abstract**

45 Achieving well-being for all, while protecting the environment, is one of the most
46 pressing global challenges of our time, and a central idea in the UN Sustainable Development
47 Goals (SDGs). We believe that integrating ecosystem services, the benefits nature provides to
48 people, into strategies for meeting the SDGs can help achieve this. Many development goals are
49 likely underpinned by the delivery of one or more ecosystem services. Understanding how these
50 services could support multiple development targets will be essential for planning synergistic and
51 cost-effective interventions. Here we present the results of an expert survey on the contributions
52 of ecosystem services to achieving SDG targets linked to environment and human well-being,
53 and review the capacity of modelling tools to evaluate SDG-relevant ecosystem services
54 interactions. Survey respondents judged that individual ecosystem services could make
55 important contributions to achieving 41 targets across 12 SDGs. The provision of food and
56 water, habitat & biodiversity maintenance, and carbon storage & sequestration were perceived to
57 each make contributions to >14 SDG targets, suggesting cross-target interactions are likely, with
58 opportunities for synergistic outcomes across multiple SDGs. Existing modelling tools are well-
59 aligned to support SDG-relevant ecosystem service planning. Together, this work identifies entry
60 points and tools to further analyze the role of ecosystem services to support the SDGs.

61

62

63

64 **1. Introduction**

65 With the formal adoption of the UN Sustainable Development Goals (SDGs) and their launch in
66 2016, governments globally are tasked with developing pathways to achieve nationally
67 prioritized targets that incorporate social, economic and environmental dimensions of
68 sustainability, moving beyond sectoral approaches of the past. Building on progress made under
69 the UN Millennium Development Goals (UN 2015*a*), the SDGs are a globally agreed upon set of
70 17 goals, 169 nested targets, and over 200 associated indicators that set the agenda for addressing
71 sustainable development challenges by 2030. Yet, practical strategies for achieving these aims in
72 unison, particularly how ecosystems can be both protected and managed to support human well-
73 being objectives, are not specified and present important and urgent research questions.

74 The wide range of themes incorporated into the SDGs, from poverty and hunger
75 alleviation to sustainable cities, economies, and ecosystems (see Table 1) point to their ambition
76 to improve the lives of the world's poorest and most marginalized communities through a multi-
77 sectoral approach. Embedded in the goals is an aim to rebuild and strengthen the integrity and
78 function of ecosystems to secure the benefits they provide to both current and future generations
79 (UN 2015*b*, UN Secretary-General 2014). In order for the SDGs to be achieved, national
80 strategies must be built on sound science and engagement of local stakeholders (Griggs et al.
81 2014, LPFN 2015, Mbow et al. 2014), and they must be sensitive to inherent interactions across
82 goals and targets (ICSU ISSC 2015, Nilsson et al. 2016).

83 Biodiversity, ecosystems and the services they provide underpin all dimensions of
84 human, societal, cultural and economic well-being (Folke et al. 2016, MEA 2005, Naeem et al.
85 2012). However, much of human economic and social development has come through the
86 unsustainable exploitation of ecosystems (MEA 2005, Raudsepp-Hearne et al. 2010*a*), with

87 society approaching or already surpassing a number of planetary boundaries (Steffen et al. 2015).
88 Despite intensive use of many ecosystems and substantial improvements in many aspects of
89 development over the past century (UNDP 2015), human well-being has yet to reach a minimum
90 acceptable level for all people worldwide (Raworth 2012). An estimated 795 million people
91 remain undernourished (FAO 2015), and access to education, health, employment and wealth is
92 distributed highly unevenly across societies (UNDP 2015, World Economic Forum 2016). To
93 realize the ambitions embodied in the SDGs, it will be essential to manage ecosystems to protect
94 nature and the sustainable supply of, as well as equitable access to, the benefits and services they
95 provide (DeClerck et al. 2016). Such efforts should increasingly be informed by regional, global
96 and thematic assessment work that is currently being undertaken by the Intergovernmental Panel
97 on Biodiversity and Ecosystem Services (IPBES), amongst others.

98 Numerous articles have highlighted the importance of integrating environmental science
99 into decision-making processes for the SDGs (ICSU ISSC 2015, Norström et al. 2014,
100 Rockström and Falkenmark 2015, Stafford-Smith 2014, Wood and DeClerck 2015) and for
101 understanding interactions between distinct sustainability targets (ICUS ISSC 2015, Nilsson et
102 al. 2016). According to a review of the targets and goals by the International Council for Science
103 (ICSU ISSC 2015), all SDG goals benefit to some degree from ecosystem protection, restoration
104 and sustainable use. Sound ecological management is required not just to constrain the
105 environmental costs of meeting development these goals, but also to enhance and sustain flows
106 of ecosystem services to humanity. Achievement of higher order social and economic goals is
107 dependent on a healthy biosphere (Folke et al. 2016).

108 For policy makers to embrace a development approach where the environment (i.e.
109 natural capital) is managed to achieve multiple objectives, there must be a sound understanding

110 of how the services provided by nature can contribute to individual or multiple SDG targets. It
111 will be important for landscape managers implementing policy directives to know how these
112 services are produced and affected by human activities across their landscapes to effectively
113 manage for them. Over the past two decades, significant progress has been made to identify ways
114 in which ecosystems benefit people and on the feedbacks between management actions and their
115 impacts on single and bundles of ecosystem services (Diaz et al. 2015, Maes et al. 2012,
116 Rausepp-Hearne et al. 2010b, Renard et al. 2015). Synthesizing this knowledge in the context of
117 the SDGs, at this early point in their uptake, will help define a path forward on how best make
118 use of the current knowledge of ecosystem services to achieve targets under the UN directive for
119 a holistic approach (UN 2015b), as well as to identify opportunities for cross-sectoral
120 collaborations for addressing interrelated SDGs.

121 Similarly, rapid progress has been made over the past decade on evaluating and
122 integrating ecosystem services into landscape planning with the emergence of modelling tools
123 and high-resolution spatial datasets. Ecosystem service models provide important tools to
124 facilitate national and regional decision-making by assessing service trade-offs and synergies
125 across multiple sectors under diverse management scenarios (e.g. Guerry et al. 2015, Mulligan
126 2015, Ruckelshaus et al. 2015, Villa et al. 2014), moving away from single-goal oriented
127 approaches. IPBES has recently led efforts to review and summarize existing modelling tools to
128 guide their use in regional, global and thematic assessments as well as outlining best-practices
129 for policy-makers in the use of these tools (Ferrier et al. 2016). However, guidance on how and
130 when ecosystems and their services can be managed to deliver on specific and/or multiple human
131 development targets remains poorly articulated and difficult for policy-makers to incorporate
132 into national development plans.

133 The goal of this paper is to summarize current understandings on the potential role of
134 ecosystem services to contribute to the SDGs and thereby outline a path forward for their
135 incorporation into national SDG policy considerations and landscape planning. We consulted
136 ecosystem service and development experts via a survey on their perceptions of the contribution
137 of each ecosystem services to SDG targets. We use information gathered through this survey and
138 a review of current modelling tools to address the following questions: (i) what are expert
139 perceptions regarding potential of ecosystem services to contribute to attainment of the SDGs?;
140 (ii) where are cross-target or cross-goal interactions likely to occur based on these perceptions?;
141 and (iii) are current modelling tool capacities adequately aligned to support policy planning
142 around these interactions?

143

144 **2. Materials and Methods**

145 *2.1 ES-SDG linkages*

146 We conducted an anonymous online survey to evaluate linkages between SDG targets and 16
147 specific ecosystems services taken from the TEEB ecosystem services typology (TEEB 2010,
148 Table 2). The 16 selected ecosystem services include provisioning, regulating, supporting and
149 cultural services. An online survey tool (SurveyMonkey) was used to create the survey and was
150 sent out from April 29th to May 30th, 2016 through academic and professional listservs to
151 ecosystem service experts. A second round of the survey was conducted from March 15th to
152 March 23rd, 2017 with the aim of broadening the profile of respondents to include greater
153 representation from development and practitioner communities. Contacted organizations include
154 the network mailing lists of: Ecosystem Services Partnership (ESP), The Economics of
155 Ecosystems and Biodiversity (TEEB), Intergovernmental Panel on Biodiversity and Ecosystem

156 Services (IPBES), ECOLOG, CGIAR Water Land Ecosystems and its program partners, CGIAR
157 Ecosystem Services and Resilience, UN Sustainable Development Solutions Network (SDSN),
158 Natural Capital Project, Institute International Sustainable Development, Science for Nature and
159 People Partnership (SNAPP) working group members involved in this study, as well as directed
160 emails to researcher and practitioners in the field (full list of contacted organizations in SM2).
161 We used a snowball technique to increase participation, asking respondents to forward the survey
162 to qualified colleagues. This is a non-probability approach, and thus we rely on descriptive rather
163 than statistical analysis of the collected data.

164 Survey respondents were asked to identify their highest academic qualification,
165 institutional affiliation type, discipline or area of expertise, landscape of expertise and their
166 number of years experience (<1 year, 1-5 years, 5-10 years, >10 years) working on ecosystem
167 services (round 1) or development issues (round 2). Respondents in the second survey round
168 were additionally asked to identify the use of ecosystem service concepts in their work from
169 ‘Never, Rarely, Occasionally’ to ‘Frequently’. We only consider respondents with an reported
170 academic degree and/or more than one year of experience in ecosystem service (round 1) or
171 development (round 2) to ensure minimum qualifications to be considered an expert. We further
172 exclude respondents in round 2 who ‘never’ or ‘rarely’ used ecosystem service concepts, as we
173 consider these respondents less likely to provide informed responses on the roles of ecosystem
174 services in the SDGs. Full copies of the survey tools can be found in the Supplementary Material
175 (SM3).

176 The survey aimed to gather expert views on, primarily, whether good management of
177 each of the 16 ecosystem services could contribute to specific SDG targets, and, secondarily,
178 how important these ecosystem service flows are to achieving the SDG target in question (see

179 SM3 for copy of the survey). A wide range of practices can be considered “good management”
180 (for instance optimization for a single service at the expense of others) and this may vary with
181 socio-ecological context. We intentionally used the term “good management” in the phrasing of
182 the question to allow for individual interpretation by experts. We requested that respondents
183 choose up to three ecosystem services in line with their expertise and evaluate their potential
184 contribution to targets under one to two SDG goals they felt competent to assess. For each
185 selected ecosystem service-SDG target combination (ES-T), respondents were asked i) if they
186 ‘Agreed’, ‘Disagreed’ or ‘Didn’t know’ whether good management of the selected ecosystem
187 service could directly or indirectly help to attain the stated target; ii) to rank the importance of
188 the ecosystem service contribution to target achievement on a four-point scale from ‘Not
189 important’ to ‘High’; and iii) to assess confidence in their evaluation of this ES-T relationship on
190 a five-point scale from ‘Very Low’ to ‘Very High’. Median responses were used in the analysis
191 of these data.

192 Due to the large number of SDG targets ($n = 169$), we reduced the number included in the
193 survey by excluding those targets for which there was no clear environmental link (e.g. reducing
194 substance abuse or improving access to reproductive health-care services) and policy-oriented
195 targets (e.g. new laws or financial mechanisms; see SM1 for list of included and excluded
196 targets). This left 44 targets across 12 SDGs for consideration (Table 1). Linkages between
197 ecosystem services and the 125 excluded SDG targets may exist but were not evaluated here.

198 We identify ES-T combinations with perceived support from pooled survey responses (an
199 analysis treating each survey round independently is found in SM5). By “support” we mean that
200 multiple experts judged an ecosystem service could positively contribute to a target, and that the
201 experts were confident in their assessments. Our criteria for levels of support were as follows:

202 strong expert support was defined as ES-T combinations that: i) were evaluated by more than
203 five respondents, ii) of which more than 75% agreed that the ecosystem service could contribute
204 positively to the target, and iii) the median ranked confidence in this assessment was ‘High’ or
205 above. Those ES-T combinations with fewer than five responses or where only 50-75% of
206 experts responded that there could be a positive contribution were classified as having
207 insufficient or weak expert support and were not considered further in our analysis. We also
208 excluded combinations where less than 50% of respondents judged good management of the
209 ecosystem service to contribute to attainment of the target as they were considered to have
210 uncertain or no support from experts.

211 Of the ES-T combinations classified by the authors as having strong expert support, we
212 highlight those combinations where the median response to the question on the importance of the
213 ecosystem service contribution to target attainment was ranked as ‘High’ as focal points for
214 policy action. We focus on these “High importance” ES-T combinations because decisions
215 affecting such services are expected, based on expert response, to have the greatest potential
216 impact on SDG outcomes. Finally, we tabulate the co-occurrence of expert supported ecosystem
217 services contributions to common targets to detect likely points of cross-service and cross-target
218 interactions, i.e. where potential exists for synergies and trade-offs. We used the program Gephi
219 v3 0.9.1 (Bastian et al. 2009) to create bipartite network diagrams to visualize these ecosystem
220 service contributions of ‘High’ perceived importance to each of the assessed SDG targets.

221

222 *2.2 Review of modelling tools for evaluating ES-SDG linkages*

223 We reviewed current ecosystem service modelling tools to assess their capacity to inform
224 ecosystem service trade-offs important to SDGs identified from the survey results. To identify

225 ecosystem service models commonly in use, we searched Google Scholar for articles with the
226 following key search terms, individually or in combination, *ecosystem, *ecosystem service,
227 *modelling, as well as individual ecosystem service names, coupled with *terrestrial and *urban.
228 We included only articles published before 1 April 2016. We reviewed the cited references in
229 these papers for additional modelling tools and followed up with targeted web searches to
230 identify tool platforms, applications and documentation. We searched United States
231 Environmental Protection Agency's online [EcoService Model Library](#) and GIZ's [ValuES portal](#)
232 to identify additional modelling tools. To be included in our review, tools needed to: i) address
233 more than a single ecosystem service at the landscape-level or larger (so as to be relevant for
234 trade-off assessments), ii) be a publically accessible 'off-the-shelf' tool and not a proprietary
235 product, iii) not be tied to a specific geographic location or landscape (e.g. Vermont forests), and
236 iv) be spatially explicit. For models meeting these criteria we reviewed their stated capacity to
237 evaluate the 16 ecosystem services included in the expert survey. In addition, tools were
238 classified as ecosystem process, ecosystem service, or integrated assessment models. 'Ecological
239 process' tools are those able to evaluate ecological functions and drivers that underpin ecosystem
240 service provision (e.g. soil erosion, infiltration, pollination) but require post-processing to
241 evaluate an ecosystem service (i.e. human benefit) (Vigerstol and Aukema 2011); 'ecosystem
242 service' tools connect an ecosystem function to a real or estimated local population benefit;
243 finally 'integrated assessment models' are tools which couple multiple ecological, social and/or
244 economic sub-models to predict changes in ecosystem function, services and/or economy
245 resulting from policy outcomes (Jakeman and Letcher 2003). For each we also recorded their
246 method of analysis (i.e. statistical, process-based, Bayesian, optimization), focal biome, ability to
247 estimate service delivery or demand, economic valuation approach and ease of use. A list of all

248 models, criteria and references for each model are provided in Supplementary Material (SM4).

249

250 **3. Results**

251 *3.1 Survey Results*

252 *3.1.1 Summary of survey responses*

253 In the first survey round, 328 individuals participated, of whom 169 provided opinions on the
254 contribution of at least one ecosystem service to one SDG target. In the second survey round,
255 aimed to reach additional experts in development communities, 231 individuals initiated the
256 survey and 123 completed at least one ecosystem service – target (ES-T) evaluation. In total, this
257 translated into 3281 and 2550 unique ES-T evaluations completed by respondents in the two
258 surveys rounds.

259

260 *3.1.2 Profile of survey respondents*

261 Based on descriptive qualities provided by respondents, the two survey rounds reached a broad
262 array of ecosystem service and development experts. Respondents spanned the five major
263 continents with 27% of respondents from North America, 22% Europe, 17% Asia, and ~10%
264 from both Latin America and Africa. Experts worked in a mix of institutional settings (14%
265 research, 14% government, 16% non-government, 10% international organizations and 8%
266 private), with slightly greater representation from academic institutions (33%). The majority of
267 respondents held a masters or doctoral degree (40% and 47%, respectively) with 5 to 10 or more
268 years of experience (19% and 43%, respectively). Only 3% of respondents indicated no degree
269 and 3.5% had less than one year of experience or no indicated experience and were excluded in
270 the analysis. Across the surveys, respondents predominantly worked within agriculture, ecology,

271 natural resource management sectors though many also worked in interdisciplinary and
272 sustainability sciences (SM5.1 for detailed respondent group profiles). The profile of survey
273 respondents who initiated but did not complete the surveys had very similar distributions of
274 background and institutional traits as those completing the survey (See SM5.2). Survey data
275 were pooled across the two rounds in subsequent analyses.

276

277 *3.1.3 Ecosystem Service-SDG target evaluation rate*

278 Respondents' evaluations were unevenly distributed across SDG goals and across
279 ecosystem services. While almost all possible ecosystem service-target (ES-T) contributions
280 were evaluated at least once, the distribution of responses was skewed towards SDG1 No
281 Poverty, SDG2 Zero Hunger, SDG6 Clean Water, and SDG15 Life on Land (SM6.1). The most
282 frequently evaluated services were provision of food and water, habitat & biodiversity
283 maintenance, and water quality services. Despite the high number of respondents pooled across
284 both surveys, several ecosystem services were only selected for evaluation by a small number of
285 experts ($n < 30$), including air quality, raw materials, genetic resources, pest and disease control,
286 and pollination services, suggesting that these services may not have been adequately evaluated
287 to identify all potential linkages. Because of the low response rate for these ES-T combinations,
288 many failed to meet our minimum threshold of five evaluations and were excluded from further
289 evaluation, potentially under-representing the contribution these services could make towards the
290 SDGs. Possible explanations for low response rates for these services include i) low familiarity
291 or fewer people working on the service, ii) low perceived importance or priority relative to other
292 ecosystem services, or iii) the length of the survey and limit of selecting only three services to
293 evaluate.

294

295 *3.1.4 Expert perceptions of ecosystem service contribution to SDG targets*

296 From a total of 704 potential ES-T combinations, there was strong support for 231 unique
297 combinations. The majority of remaining ES-T combinations evaluated (n = 364) were classified
298 as having weak or insufficient support, primarily because they had less than five respondents,
299 rather than due to low agreement or confidence. In these cases, inferences regarding the
300 existence or importance of ES-T interactions is considered to be too weak for inclusion in the
301 analysis. Fourteen ES-T interactions received more than 5 responses but less than 50%
302 agreement that the ecosystem service in question would contribute to target attainment; these
303 were considered to have uncertain support and a further 95 ES-Ts were not assessed.

304

305 *3.1.5 Perceived importance of ecosystem service – target contributions*

306 Although Figure 1 illustrates areas where experts perceived ecosystem services to make a
307 contribution, respondents did not rate all contributions with equal *importance* for SDG target
308 attainment. Amongst the 231 ES-T combinations with strong expert support, 178 were perceived
309 to have ‘High’ importance for the attainment of the target. For 41 of the 44 assessed SDG
310 targets, at least one ecosystem service was considered to be of ‘High’ importance (Figure 2). Of
311 the 12 SDGs considered in the survey, SDG2 Zero Hunger, SDG14 Life Below Water and
312 SDG15 Life on Land, had the most number of targets thought to depend up on ecosystem service
313 contributions. Similarly, SDG6 Clean Water and SDG11 Sustainable Cities were judged as
314 having ecosystem services make important contributions to 40-50% of their targets. In
315 subsequent sections we focus on only these ES-T contributions of ‘High’ perceived importance.

316

317 *3.1.6 Network analyses of important ecosystem service contributions to targets*

318 We used a bipartite network analysis to plot the 178 ES-T interactions of ‘High’ perceived
319 importance by each SDG target (Figure 3). In the pooled surveys, provision of food and water
320 and habitat & biodiversity maintenance services were the most frequently evaluated and also
321 perceived as contributing to the greatest number of distinct targets (21, 21 and 26 targets
322 respectively) followed by carbon storage & sequestration (14). Water quality, water regulation,
323 raw material provisioning and recreation & tourism each contributed to 10 or more targets. On
324 the flip side, goals SDG1 No Poverty, SDG2 Zero Hunger, SDG6 Clean Water and SDG15 Life
325 on Land were thought to receive highly important contributions from the greatest number of
326 distinct ecosystem services, with 5, 12, 7 and 14 ecosystem services contributing to targets
327 within each SDG respectively (Figure 3).

328

329 *3.1.7 Poverty-agriculture-water-nature nexus – Opportunities for synergies?*

330 To draw out potential interactions and opportunities for synergies in perceived ES-T
331 contributions, we plotted the network diagram of important ecosystem service contributions
332 identified by experts for the most highly connected goals: SDG1 No Poverty, SDG2 Zero
333 Hunger, SDG6 Clean Water and SDG15 Life on Land targets (Figure 5). While many of the
334 services are thought to contribute to at least two goals, food provision, water provision, and
335 habitat & biodiversity maintenance were perceived as central to all four goals. These three
336 services represent potentially important interaction spaces for trade-offs or synergies across
337 between services. As a result, it may be pertinent for policy makers to consider these services in
338 tandem for the attainment of these four SDGs in concert.

339

340 *3.1.8 Anticipated interactions among ecosystem services for the SDGs*

341 Results from surveyed experts suggest that at least one ecosystem service was deemed important
342 for the attainment 41 of the 44 targets and many targets were thought to receive important
343 contributions from two or more services (Figure 2b). When designing interventions around
344 targets underpinned by multiple services it is be critical to assess and predict how landscape
345 decisions change the provision underpinning each service to identify cost-effective and synergist
346 solutions. Interventions designed to address one target by increasing supplies of a single
347 ecosystem service (e.g. tree planting to increase carbon sequestration) may cause an increase in a
348 second (i.e. synergies, e.g. erosion control) but declines in a third (i.e. trade-offs, e.g. reduced
349 food production). In order to understand which combinations of services will most frequently
350 need to be managed in concert when tackling the SDGs we tabulated the total number of pair-
351 wise sets of ecosystem services perceived to contribute to individual targets across all SDG goals
352 (Figure 5a). The most common combinations of services involved food and water provision and
353 habitat & biodiversity maintenance together and in combination with most other ecosystem
354 services. Spatial models that estimate both overall direction (i.e. increase or decrease) as well as
355 spatial variation in the provision of multiple services can help to predict the outcomes of
356 proposed interventions on communities across the landscape.

357

358 ***3.2 Modelling tool review***

359 *3.2.1 Modelling tool capacities*

360 Our Internet search identified 67 modelling tools addressing ecosystem processes and services.
361 Of these, 42 were excluded from our assessment because they were either under proprietary
362 rights, single ecosystems service models, conceptual assessment frameworks, under

363 development, or no longer in use. This left 25 modelling tools accessible to policy-makers and
364 potentially capable of assessing trade-offs in ecosystem functions or services at the landscape
365 scale or larger (Table 3).

366 Most of the tools evaluated did not incorporate the capacity to dynamically assess
367 synergies or trade-offs between multiple services, rather users *post hoc*, can combine model
368 outputs for a number of ecosystems services to assess trade-offs. At the time of review, the
369 modelling tools examined produce outputs for, on average, seven of the ecosystem services
370 considered in our assessment (Table 3), however some of these may have since evolved to
371 include more or other services (e.g. Co\$tingNature). Reviewed models most commonly provided
372 the option to assess the following ecosystem services: water provisioning (n = 19), carbon
373 storage & sequestration (17), food provision (16), nutrient cycling (14), water quality (14), and
374 erosion control (14). Fewer models provide options to assess moderation of extremes (5), pest &
375 disease control (4), pollination (3), and air quality (2) and none for genetic resource partitioning.
376 Cultural services were separated into ‘cultural and spiritual’, ‘aesthetic’, and ‘recreation and
377 tourism’ for which a moderate number of tools (n=5-8) were available (Table 3).

378 Comparing the capacity tools to assess all 16 ecosystem services, we determined which
379 pair-wise sets of ecosystem service most commonly co-occur within single modelling tools and
380 can thus assess synergies and trade-offs (Figure 5b). The majority of tools evaluated are capable
381 of producing spatially-explicit outputs assessing co-occurrence of provisioning of food and
382 water, carbon storage & sequestration and nutrient cycling services. In particular, water
383 provisioning and carbon storage & sequestration services has the greatest number of tools
384 capable of offering estimates of both (n = 15), followed closely by water provision – erosion
385 control (n = 14), water provision – food provision (n = 12), and water provision – water quality

386 (n = 12). As well there were a large number of tools to evaluate habitat & biodiversity
387 maintenance – cultural, spiritual & aesthetic (n =13). A smaller number of tools (<8 models)
388 were collectively able to inform interactions between most of the remaining ecosystem services.
389 However, there is a subset of ecosystem services interactions between genetic resources, air
390 quality, pollination, pest control and cultural & spiritual services that none of the reviewed tools
391 are able to assess.

392

393 *3.2.2 Correspondence of modelling tool capacity for SDG planning needs*

394 We assessed the capacity of existing modelling tools to evaluate pairs of SDG-relevant
395 ecosystem services. Tools that evaluate the magnitude, variability and direction of changes in
396 pairs of ecosystem services can be used to compare the impact of a single intervention at the
397 landscape scale. There was reasonable correspondence between modelling tool capacities and the
398 most common ecosystem service combinations that we identified from survey responses
399 (comparison of Fig 5a and 5b). In particular, there were a high number of tools capable of
400 estimating provision of food, water and raw materials, carbon storage & sequestration, nutrient
401 cycling and erosion, water quality and water regulation. There amongst these tools, there was
402 also reasonable modelling capacity to assess habitat & biodiversity maintenance and recreation
403 services, but no capacity to estimate change in genetic resource provisioning.

404

405 **4. Discussion**

406 *4.1 A perceived role for ecosystem services to support the SDGs*

407 The Sustainable Development Goals represent an agenda to end poverty and increase prosperity
408 while protecting the planet from degradation (UN 2015a). Biodiversity and ecosystem

409 conservation form the basis of two SDG goals (14 & 15), and their contribution to ecosystem
410 services and human well-being underpins the achievement of all other goals (ICSU ISSC 2015).
411 In this paper we present results from a large survey of ecosystem service and development
412 experts of their perceptions of ecosystem service contribution to the attainment of the SDGs. We
413 then review the capacity for spatial modelling tools to support landscape planning by modelling
414 services perceived to contribute to the SDGs. Despite the large size of the survey and high
415 number of perceived contributions of ecosystem services to targets, this assessment is likely
416 incomplete due to unbalanced representation of respondents across disciplines and uneven
417 evaluation across goals (see discussion of survey limitations, section 4.6). We present our results
418 as a first attempt to map ES-T contributions and as a starting point for consideration of
419 ecosystem services in national and landscape-level project design for the SDGs.

420

421 ***4.2 Key Findings***

422 The results of our survey highlight where ecosystem services are perceived contribute to the
423 achievement of 41 SDG targets, and illuminate potential points of interactions across services. In
424 particular, provision of food and water, maintenance of habitat & biodiversity and carbon storage
425 & sequestration were identified as key services, each perceived to contribute to targets across
426 seven or more SDG goals. These four ecosystem services were commonly linked to the same
427 individual targets, alongside water quality, water regulation, and recreation & tourism. **Because**
428 **ecosystem services were evaluated in isolation, interactions between services were not captured**
429 **in survey responses.** Many studies have shown that services are often bundled (Raudsepp-Hearne
430 et al. 2010b, Renard et al. 2015). However, trade-offs around new land use changes can occur
431 because services are produced at different rates and across different spatial scales and lead to

432 differences in provision across communities and through time (Mulligan 2015). Thus, managing
433 landscapes to maintain or enhance this suite of ecosystem services, now and into the future, is
434 likely to be particularly important for achieving multiple SDG targets in concert. Many of the
435 reviewed modelling tools are also capable of evaluating these combinations of services,
436 especially those involving provisioning services.

437 The alignment of survey responses and modelling tools suggest that there are significant
438 entry points and resources to support landscape planning for the SDGs. The four cross-cutting
439 services **identified from expert responses** (food provision, water provision, carbon storage and
440 habitat & biodiversity maintenance), plus erosion control, coincide with the most commonly
441 mapped ecosystem services as identified in a review of previous studies (Martinez-Harms and
442 Balvanera 2012). Furthermore, these services are most commonly mapped at the regional (10^3 -
443 10^5 km) and national scale (Martinez-Harms and Balvanera 2012), making them particularly
444 relevant for country-**level evaluations and project design to address challenges presented by**
445 SDGs. The prevalence of research, funding and analysis of these ecosystem services in the
446 literature suggests a greater awareness of their dynamics over others. This may have resulted in
447 greater positive perceptions for their contribution to SDG targets, potentially at the expense of
448 other ecosystem services that are less well researched and/or funded. Together these suggest that
449 less well-evaluated services in our survey should not be discounted, but rather that additional
450 research is needed to establish their contribution to the multiple dimensions of human well-being
451 captured in the SDGs.

452

453 ***4.3 Ecosystem service-based management for synergistic SDG outcomes***

454 Our network analysis shows, **based on expert perceptions**, that SDG targets rarely dependent on a

455 single ecosystem service and that most services are thought to contribute to targets across more
456 than one goal (Figure 3). This implies that policy-makers working to achieve SDG targets
457 reviewed will likely need to manage for multiple ecosystem services (i.e. bundles) in order to
458 realize these positive benefits. This will be particularly important for targets at the *poverty-food-*
459 *water-environment* nexus where a large a number of targets were perceived to rely on common
460 services. Diverse bundles of ecosystem services are generally associated with a large number of
461 regulating services in addition to provisioning services (Raudsepp-Hearne et al. 2010b), and this
462 is supported by perceptions captured in our survey with carbon storage & sequestration, water
463 regulation and water quality judged to contribute to a wide range of targets.

464 In our survey, experts were only asked if the “good management” of a given ecosystem
465 service under consideration could help to attain the SDG target. Interactions of the ecosystem
466 service with other services may or may not have been considered by respondents when providing
467 an evaluation. It is recognized that management for a single service may not be effective or
468 efficient, and often comes at the expense of many other services. Past efforts focused on
469 increasing the supply of provisioning services to meet development objectives have frequently
470 occurred at the expense of regulating services (MEA 2005, Pereira et al. 2005). It is not possible
471 from our results to infer whether experts considered such interacts in their evaluation, and if this
472 affected their ranking for the importance of the service. It is possible that when the associated
473 interactions with other ecosystem services in a landscape are considered, that the importance of
474 the contribution of any one service declines.

475 The adoption of an ecosystem-service based approach, by policy-makers and
476 practitioners, which explicitly considers the interactions across services and goals, could help to
477 better balance short-term efforts to increase provision of food, water and other material resources

478 with the suite of regulating services supporting their long-term supply. We note that many
479 technical and policy-oriented SDG targets were not included in our survey and we recognize that
480 policy makers will need to take a multi-pronged approach including legislative, economic and
481 socio-technical initiatives to achieve development priorities.

482

483 ***4.4 The role of modelling tools to incorporate ecosystem services into SDG planning***

484 Making ecosystem services tangible to decision-makers through biophysical quantification is a
485 critical step towards their successful inclusion in policies and planning frameworks (Cowling et
486 al. 2008, Egoh et al. 2012). In their recent review of models and scenarios, IPBES highlights that
487 models can be an effective means of articulating the relationships between nature, people and
488 well-being, and allow the exploration of the projected consequences of alternative policy
489 scenarios to inform decision-making (Ferrier et al. 2016). For instance, while an intervention
490 may increase service supply overall, it does not necessarily translate into improved SDG target
491 attainment if access increases for a privileged group (e.g. commercial irrigators withdrawing
492 reservoir water) at the expense of others targeted by the intervention (e.g. smallholder or
493 downstream floodplain farmers). To date, a large number of ecosystem service models have been
494 developed and are increasingly being used at local, national, and regional levels to inform
495 landscape planning, priority setting and evaluation of investment trade-offs (Maes et al. 2013,
496 Mulligan 2012, Mulligan et al. 2013, Ruckelhaus et al. 2013, Ferrier et al. 2016).

497 Across the reviewed modelling tool platforms, we found there was a stated capacity to
498 estimate nearly all ecosystem services except for genetic resource provisioning. At the time of
499 review, most models estimated food and water provisioning in combination with an assortment
500 of regulating and cultural services, though none was able to model them all. This may have

501 changed since carrying out the study. This suggests that a strong and possibly growing modelling
502 capacity exists to support and inform interactions around key ecosystem service identified by
503 experts, particularly interactions across SDG 1, 2, 6 and 15. There was, however, generally lower
504 stated capacity to evaluate animal-mediated services (pollination, pest & disease control) and
505 urban-related services (air pollution, moderation of extremes) or their trades-offs. This may be
506 due to the inherent difficulty in predicting animal behaviours and a greater focus in the
507 ecosystem services community on rural landscapes (although there is a growing literature on
508 urban ecosystem services, e.g. Baró et al. 2014, Escobedo et al. 2011). These results complement
509 and deepen the model review undertaken by IPBES (Ferrier et al. 2016) by looking at the
510 specific ecosystem service interactions which models are capable of assessing and identify
511 additional gaps in current tools that will need to be addressed in order to capture the range of
512 service interactions expected. It was not, however, within the scope of this paper to assess the
513 efficacy or accuracy of the tools' service estimations and additional review is needed to
514 determine quality of model outputs.

515

516 ***4.4 The perceived importance of Habitat & Biodiversity Maintenance***

517 Of reviewed ecosystem services, habitat & biodiversity maintenance was most frequently
518 evaluated and, as a consequence, had the greatest number of perceived contributions to
519 attainment of SDG targets. Many of these perceived contributions were linked to targets under
520 SDG 14 (Life Below Water) and SDG 15 (Life on Land) for the direct protection of species and
521 the environment. A significant number were also thought to contribute to six other SDGs ranging
522 from No Poverty (SDG1) to Sustainable Cities (SDG11). In many ecosystem service
523 frameworks, biodiversity is often not considered an service *sensu stricto* (Naeem et al. 2002), but

524 rather the interactions amongst species and their environment are the means by which other
525 ecosystem services are produced (Balvanera et al. 2006, Cardinale et al. 2012, Duncan et al.
526 2015, Ricketts et al. 2015). There is growing evidence that greater levels of biodiversity support
527 enhanced and/or more stable provision of other services (e.g. insect diversity – pollination,
528 Garibaldi et al. 2013; crop diversity – yield, Smith et al. 2008; tree diversity – carbon storage,
529 Poorter et al. 2015). Where species conservation was not the primary objective of the SDG
530 target, we expect that many of the contributions from habitat & biodiversity maintenance
531 identified by experts to these latter goals were perceived as indirect in nature.

532 This dual contribution of habitat & biodiversity maintenance to the SDGs, both direct and
533 indirect, may pose a significant challenge for its accurate consideration in landscape
534 management plans. While many of the evaluated modelling tools had the capacity to evaluate the
535 service this was achieved primarily by calculating the change in area of land cover. None of the
536 models reviewed included an explicit modelling of biodiversity as an outcome of landscape
537 change. Previous reviews of ecosystem service models (Crossman et al. 2013 and Martinez-
538 Harms and Balvanera 2012) have also found that despite a long disciplinary history of modelling
539 habitat suitability, population dynamics and biodiversity hotspots in the ecological and
540 environmental sciences, methods to model biodiversity change remain less common in the
541 ecosystem service literature (Crossman et al. 2013). Few, if any models, incorporate both direct
542 impact of land use changes on biodiversity, and its indirect impact on the provision of other
543 services. This is a critically missing component in our ability to accurately assess the impacts of
544 landscape change on ecosystem service provision. Thus, there is a need to develop a more
545 mechanistic inclusion of biodiversity's indirect role in estimating other ecosystem functions and
546 services (e.g. Duncan et al. 2015, Gonzalez et al. 2009) to better appreciated its role in achieving

547 the SDGs.

548

549 ***4.6 Survey limitations***

550 Our survey acknowledged *a priori* a role for ecosystem services in achieving the SDGs and
551 sought out expert knowledge to identify where management of ecosystem services could most
552 contribute to specific development targets. We observed a broad tendency for respondents to
553 agree that ecosystem services could contribute to almost all of the 44 selected targets evaluated.
554 This bias is not unexpected given respondents' background, self-selection to take the survey, and
555 the fact that respondents were asked to select their own areas of expertise. We found that food
556 provisioning and habitat & biodiversity maintenance services and SDG 2, 6 and 15 were most
557 commonly selected to evaluate (SM4a), likely reflecting the larger number of survey respondents
558 from agriculture, ecology, natural resource management and sustainability sciences (SM5). We
559 used a snowballing technique to access this "hidden community" of ecosystem service and
560 development experts (Sudman and Kalton 1986), an approach that can also introduce bias into
561 the sample. In general, individuals receiving the survey are more likely to forward it on to
562 colleagues within their own social network who may share common understandings and
563 perspectives, thus amplifying certain perceptions over others. As a result, this approach is
564 effective in identifying where there is strong agreement in understanding around particular
565 ecosystem services, but can result in other perspectives or services being under represented.

566 This sampling approach may explain why certain ES-T combinations were evaluated
567 much more frequently than others, resulting in under-evaluation of certain sets of ecosystem
568 services or goals. For example, a large body of literature exists on the role of nutrient cycling and
569 erosion control on downstream coastal water quality (Barbier 2012, Carpenter et al. 1998,

570 Vitousek et al. 1997). However, the contribution of these services to SDG14.1 to *prevent and*
571 *significantly reduce marine pollution of all kinds, in particular from land-based activities,*
572 *including marine debris and nutrient pollution,* was evaluated as having ‘Weak’ support because
573 it was assessed by less than 5 respondents and only 5% of our respondent pool worked on coastal
574 and marine systems (SM5). Thus, we urge a strong degree of caution before excluding the
575 possibility of ES-T combinations not classified as having ‘Strong’ support, as they are highly
576 susceptible to under-evaluation due to sampling bias. Additional research and review of current
577 literature is needed on these linkages to broaden and better evaluate the evidence base for the
578 potential contribution of these ecosystem services to SDG targets.

579 **Finally, since experts were asked to evaluate ecosystem services on an individual basis,**
580 **we cannot predict from experts’ responses how two or more services contributing to a common**
581 **target are expected to interact. Additional surveys and reviews of the literature are needed to**
582 **estimate if these interactions are likely to be positive (“indivisible, reinforcing, enabling”),**
583 **neutral (“consistent”) or negative (“constraining, counteracting or cancelling”) using a scale such**
584 **as Nilsson et al 2017.**

585

586 ***4.7 Ways forward***

587 We recognize that ecosystem service management alone will be insufficient to achieve the
588 ambitious SDG agenda. Ecosystem service management will need to be paired with
589 complementary technologies and socio-institutional-based solutions in order to achieve targets
590 over the short SDG timespan (2015-2030). For example, achieving clean water targets under
591 SDG6 will require a combination of installing water treatment plants alongside catchment land
592 cover and land use management. Similarly, efforts to eradicate malaria and other emerging

593 neotropical diseases (SDG3 target 3.3) will require a suite of tools from land cover and land-use
594 management for pest and disease control, to insecticide-treated bed nets and national health
595 programs to educate and treat affected communities. In many instances socio-institutional
596 solutions may offer cheaper and quicker solutions to pressing challenges, as they require less
597 infrastructure to implement and can tackle some of the root causes of the problem (Cartwright et
598 al. 2013). However, all too often ecosystem services are undervalued in planning which can lead
599 to ineffective solution in the long term, e.g. levying of the Mississippi river to prevent flooding
600 altered the hydrology sustaining the surrounding wetlands needed to buffer the coastline against
601 storm surges (Day et al. 2007). Both socio-institutional and technology-based solutions should be
602 planned in concert rather than in competition with ecosystem-based approaches at the outset of
603 policy development to identify the most effective and enduring solutions to achieve national
604 development aims while avoiding unforeseen trade-offs with other goals.

605 To facilitate uptake of ecosystem service-based approaches for the SDGs, new output
606 indicators that speak directly to the metrics tracked in the SDG framework would be useful
607 (Ferrier et al. 2016). Indicators which report ecosystem service outcomes in terms of land area or
608 number of people affected (as is done in WaterWorld and Co\$tingNature), malnutrition rates,
609 and proportion of demographic groups with access to specific resources are likely more intuitive
610 and compelling for decision-makers than traditional biophysical or economic indicators (e.g. tons
611 of carbon, m³ of water, avoided costs). Small changes to current model outputs, for example
612 translating sediment erosion into avoided degradation or crop production into calories and
613 micronutrient availability, are possible and would provide entry points with policymakers on the
614 value of ecosystem service-based approaches. However, including these “human well-being”
615 indicators in model outputs adds another ‘step’ in the chain of estimation from ecosystem

616 function, service supply, and service use to human well-being, requiring greater model
617 simplification and potentially increasing uncertainty and errors.

618

619 **5. Conclusions**

620 Our survey results reflect broad support from ecosystem service and development experts for the
621 role of ecosystem services in supporting the SDGs. While we were not able to assess the
622 contribution of all services to all SDG targets evenly, we identify four ecosystem services that
623 are perceived to make important contributions to achieving targets across 12 different goals and
624 identify additional services expected to contribute to more select sets of targets. A large number
625 of modelling tools are already available to support policy-makers in their efforts to incorporate
626 ecosystem service approaches, which can increase the chances of achieving the ambitions set out
627 in the SDGs. By distilling expert perceptions and identifying tools, we help chart a path forward
628 for the considerations of ecosystem service and management into local and national development
629 policy plans.

630

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879 **8. Tables and Captions**

880 **Table 1.** Sustainable Development Goals and the selected targets evaluated in the expert survey

881 (see details on targets in SM1)

SDG	Title	Goal	Evaluated Targets
SDG1	No Poverty	End poverty in all its forms everywhere	1.1, 1.2, 1.5
SDG2	Zero Hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.1, 2.2, 2.3, 2.4, 2.5
SDG3	Good Health & Well-Being	Ensure healthy lives and promote well-being for all at all ages	3.3, 3.4, 3.9
SDG4	Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	
SDG5	Gender Equity	Achieve gender equality and empower all women and girls	
SDG6	Clean Water & Sanitation	Ensure availability and sustainable management of water and sanitation for all	6.1, 6.3, 6.4, 6.6
SDG7	Affordable & Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all	7.1, 7.2
SDG8	Decent Work & Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.2, 8.4, 8.9
SDG9	Industry, Innovation & Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	9.1, 9.4
SDG10	Reduced Inequality	Reduce inequality within and among countries	
SDG11	Sustainable Cities & Communities	Make cities and human settlements inclusive, safe, resilient and sustainable	11.5, 11.6, 11.7, 11.a, 11.c
SDG12	Responsible Production & Consumption	Ensure sustainable consumption and production patterns	12.2, 12.3, 12.4, 12.5
SDG13	Climate Action	Take urgent action to combat climate change and its impacts	13.1
SDG14	Life Below Water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.1, 14.2, 14.3, 14.4, 14.5, 14.7
SDG15	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1, 15.2, 15.3, 15.4, 15.5, 15.8

SDG16	Peace, Justice & Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
SDG17	Partnerships for the Goals	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

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901 **Table 2.** The 16 ecosystem services included in the expert survey modified from the original 22
 902 TEEB typology ecosystem services.

TEEB Ecosystem Service Categories	TEEB Typology	Survey Typology
Provisioning	Food	Food
	Water	Water
	Raw Materials	Raw Materials
	Genetic Resources	Genetic (Includes Medicinal, Ornamental)
	Medicinal Resources	
	Ornamental Resources	
Regulation	Air Quality Regulation	Air Quality / Purification
	Waste treatment (water purification)	Water Quality / Purification
	Moderation of extreme flows	Water Regulation / Flood Control
	Erosion prevention	Erosion / Sedimentation Prevention
	Climate regulation	Moderation of Extremes
		Carbon Storage & Sequestration
	Maintenance of Soil Fertility	Nutrient Cycling
	Pollination	Pollination
Biological Control	Pest & Disease Control	
Supporting	Maintenance of Life Cycles	Habitat & Biodiversity Maintenance
	Maintenance of Genetic Diversity	
Cultural	Spiritual Experience	Spiritual, Aesthetic, Cultural
	Aesthetic information	
	Inspiration for art, culture, design	
	Recreation & tourism	Recreation & Ecotourism
	Information Cognitive Development	

IMAGE																	Low
MIMES																	Low
Sum across Models	16	10	19	17	5	11	14	14	14	4	2	3	11	5	8	8	

†Wildlife Habitat Benefits Estimation Tool

*Food provisioning includes terrestrial crop and livestock production, fisheries and aquaculture

**Water provisioning includes both surface and groundwater provision

