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

Short Title: Ecosystem Services and the SDGs

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Abstract

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

1. Introduction

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

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

Biodiversity, ecosystems and the services they provide underpin all dimensions of human, societal, cultural and economic well-being (Folke et al. 2016, MEA 2005, Naeem et al. 2012). However, much of human economic and social development has come through the unsustainable exploitation of ecosystems (MEA 2005, Raudsepp-Hearne et al. 2010*a*), with society approaching or already surpassing a number of planetary boundaries (Steffen et al. 2015). Despite intensive use of many ecosystems and substantial improvements in many aspects of development over the past century (UNDP 2015), human well-being has yet to reach a minimum acceptable level for all people worldwide (Raworth 2012). An estimated 795 million people remain undernourished (FAO 2015), and access to education, health, employment and wealth is distributed highly unevenly across societies (UNDP 2015, World Economic Forum 2016). To realize the ambitions embodied in the SDGs, it will be essential to manage ecosystems to protect nature and the sustainable supply of, as well as equitable access to, the benefits and services they provide (DeClerck et al. 2016). Such efforts should increasingly be informed by regional, global and thematic assessment work that is currently being undertaken by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), amongst others.

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

For policy makers to embrace a development approach where the environment (i.e. natural capital) is managed to achieve multiple objectives, there must be a sound understanding of how the services provided by nature can contribute to individual or multiple SDG targets. It will be important for landscape managers implementing policy directives to know how these services are produced and affected by human activities across their landscapes to effectively manage for them. Over the past two decades, significant progress has been made to identify ways in which ecosystems benefit people and on the feedbacks between management actions and their impacts on single and bundles of ecosystem services (Diaz et al. 2015, Maes et al. 2012, Rausepp-Hearne et al. 2010*b*, Renard et al. 2015). Synthesizing this knowledge in the context of the SDGs, at this early point in their uptake, will help define a path forward on how best make use of the current knowledge of ecosystem services to achieve targets under the UN directive for a holistic approach (UN 2015*b*), as well as to identify opportunities for cross-sectoral collaborations for addressing interrelated SDGs.

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

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

2. Materials and Methods

2.1 ES-SDG linkages

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

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

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

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

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

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

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

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

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

2.2 Review of modelling tools for evaluating ES-SDG linkages

We reviewed current ecosystem service modelling tools to assess their capacity to inform ecosystem service trade-offs important to SDGs identified from the survey results. To identify ecosystem service models commonly in use, we searched Google Scholar for articles with the following key search terms, individually or in combination, *ecosystem, *ecosystem service, *modelling, as well as individual ecosystem service names, coupled with *terrestrial and *urban. We included only articles published before 1 April 2016. We reviewed the cited references in these papers for additional modelling tools and followed up with targeted web searches to identify tool platforms, applications and documentation. We searched United States Environmental Protection Agency's online EcoService Model Library and GIZ’s ValuES portal to identify additional modelling tools. To be included in our review, tools needed to: i) address more than a single ecosystem service at the landscape-level or larger (so as to be relevant for trade-off assessments), ii) be a publically accessible ‘off-the-shelf’ tool and not a proprietary product, iii) not be tied to a specific geographic location or landscape (e.g. Vermont forests), and iv) be spatially explicit. For models meeting these criteria we reviewed their stated capacity to evaluate the 16 ecosystem services included in the expert survey. In addition, tools were classified as ecosystem process, ecosystem service, or integrated assessment models. ‘Ecological process’ tools are those able to evaluate ecological functions and drivers that underpin ecosystem service provision (e.g. soil erosion, infiltration, pollination) but require post-processing to evaluate an ecosystem service (i.e. human benefit) (Vigerstol and Aukema 2011); ‘ecosystem service’ tools connect an ecosystem function to a real or estimated local population benefit; finally ‘integrated assessment models’ are tools which couple multiple ecological, social and/or economic sub-models to predict changes in ecosystem function, services and/or economy resulting from policy outcomes (Jakeman and Letcher 2003). For each we also recorded their method of analysis (i.e. statistical, process-based, Bayesian, optimization), focal biome, ability to estimate service delivery or demand, economic valuation approach and ease of use. A list of all models, criteria and references for each model are provided in Supplementary Material (SM4).

3. Results

3.1 Survey Results

3.1.1 Summary of survey responses

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

3.1.2 Profile of survey respondents

Based on descriptive qualities provided by respondents, the two survey rounds reached a broad array of ecosystem service and development experts. Respondents spanned the five major continents with 27% of respondents from North America, 22% Europe, 17% Asia, and ~10% from both Latin America and Africa. Experts worked in a mix of institutional settings (14% research, 14% government, 16% non-government, 10% international organizations and 8% private), with slightly greater representation from academic institutions (33%). The majority of respondents held a masters or doctoral degree (40% and 47%, respectively) with 5 to 10 or more years of experience (19% and 43%, respectively). Only 3% of respondents indicated no degree and 3.5% had less than one year of experience or no indicated experience and were excluded in the analysis. Across the surveys, respondents predominantly worked within agriculture, ecology, natural resource management sectors though many also worked in interdisciplinary and sustainability sciences (SM5.1 for detailed respondent group profiles). The profile of survey respondents who initiated but did not complete the surveys had very similar distributions of background and institutional traits as those completing the survey (See SM5.2). Survey data were pooled across the two rounds in subsequent analyses.

3.1.3 Ecosystem Service-SDG target evaluation rate

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

3.1.4 Expert perceptions of ecosystem service contribution to SDG targets

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

3.1.5 Perceived importance of ecosystem service – target contributions

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

3.1.6 Network analyses of important ecosystem service contributions to targets

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

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

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

3.1.8 Anticipated interactions among ecosystem services for the SDGs

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

3.2 Modelling tool review

3.2.1 Modelling tool capacities

Our Internet search identified 67 modelling tools addressing ecosystem processes and services. Of these, 42 were excluded from our assessment because they were either under proprietary rights, single ecosystems service models, conceptual assessment frameworks, under development, or no longer in use. This left 25 modelling tools accessible to policy-makers and potentially capable of assessing trade-offs in ecosystem functions or services at the landscape scale or larger (Table 3).

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

Comparing the capacity tools to assess all 16 ecosystem services, we determined which pair-wise sets of ecosystem service most commonly co-occur within single modelling tools and can thus assess synergies and trade-offs (Figure 5b). The majority of tools evaluated are capable of producing spatially-explicit outputs assessing co-occurrence of provisioning of food and water, carbon storage & sequestration and nutrient cycling services. In particular, water provisioning and carbon storage & sequestration services has the greatest number of tools capable of offering estimates of both (n = 15), followed closely by water provision – erosion control (n = 14), water provision – food provision (n = 12), and water provision – water quality (n = 12). As well there were a large number of tools to evaluate habitat & biodiversity maintenance – cultural, spiritual & aesthetic (n =13). A smaller number of tools (<8 models) were collectively able to inform interactions between most of the remaining ecosystem services. However, there is a subset of ecosystem services interactions between genetic resources, air quality, pollination, pest control and cultural & spiritual services that none of the reviewed tools are able to assess.

3.2.2 Correspondence of modelling tool capacity for SDG planning needs

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

4. Discussion

4.1 A perceived role for ecosystem services to support the SDGs

The Sustainable Development Goals represent an agenda to end poverty and increase prosperity while protecting the planet from degradation (UN 2015*a*). Biodiversity and ecosystem conservation form the basis of two SDG goals (14 & 15), and their contribution to ecosystem services and human well-being underpins the achievement of all other goals (ICSU ISSC 2015). In this paper we present results from a large survey of ecosystem service and development experts of their perceptions of ecosystem service contribution to the attainment of the SDGs. We then review the capacity for spatial modelling tools to support landscape planning by modelling services perceived to contribute to the SDGs. Despite the large size of the survey and high number of perceived contributions of ecosystem services to targets, this assessment is likely incomplete due to unbalanced representation of respondents across disciplines and uneven evaluation across goals (see discussion of survey limitations, section 4.6). We present our results as a first attempt to map ES-T contributions and as a starting point for consideration of ecosystem services in national and landscape-level project design for the SDGs.

4.2 Key Findings

The results of our survey highlight where ecosystem services are perceived contribute to the achievement of 41 SDG targets, and illuminate potential points of interactions across services. In particular, provision of food and water, maintenance of habitat & biodiversity and carbon storage & sequestration were identified as key services, each perceived to contribute to targets across seven or more SDG goals. These four ecosystem services were commonly linked to the same individual targets, alongside water quality, water regulation, and recreation & tourism. Because ecosystem services were evaluated in isolation, interactions between services were not captured in survey responses. Many studies have shown that services are often bundled (Raudsepp-Hearne et al. 2010*b*, Renard et al. 2015). However, trade-offs around new land use changes can occur because services are produced at different rates and across different spatial scales and lead to differences in provision across communities and through time (Mulligan 2015). Thus, managing landscapes to maintain or enhance this suite of ecosystem services, now and into the future, is likely to be particularly important for achieving multiple SDG targets in concert. Many of the reviewed modelling tools are also capable of evaluating these combinations of services, especially those involving provisioning services.

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

4.3 Ecosystem service-based management for synergistic SDG outcomes

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

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

The adoption of an ecosystem-service based approach, by policy-makers and practitioners, which explicitly considers the interactions across services and goals, could help to better balance short-term efforts to increase provision of food, water and other material resources with the suite of regulating services supporting their long-term supply. We note that many technical and policy-oriented SDG targets were not included in our survey and we recognize that policy makers will need to take a multi-pronged approach including legislative, economic and socio-technical initiatives to achieve development priorities.

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

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

Across the reviewed modelling tool platforms, we found there was a stated capacity to estimate nearly all ecosystem services except for genetic resource provisioning. At the time of review, most models estimated food and water provisioning in combination with an assortment of regulating and cultural services, though none was able to model them all. This may have changed since carrying out the study. This suggests that a strong and possibly growing modelling capacity exists to support and inform interactions around key ecosystem service identified by experts, particularly interactions across SDG 1, 2, 6 and 15. There was, however, generally lower stated capacity to evaluate animal-meditated services (pollination, pest & disease control) and urban-related services (air pollution, moderation of extremes) or their trades-offs. This may be due to the inherent difficulty in predicting animal behaviours and a greater focus in the ecosystem services community on rural landscapes (although there is a growing literature on urban ecosystem services, e.g. Baró et al. 2014, Escobedo et al. 2011). These results complement and deepen the model review undertaken by IPBES (Ferrier et al. 2016) by looking at the specific ecosystem service interactions which models are capable of assessing and identify additional gaps in current tools that will need to be addressed in order to capture the range of service interactions expected. It was not, however, within the scope of this paper to assess the efficacy or accuracy of the tools' service estimations and additional review is needed to determine quality of model outputs.

4.4 The perceived importance of Habitat & Biodiversity Maintenance

Of reviewed ecosystem services, habitat & biodiversity maintenance was most frequently evaluated and, as a consequence, had the greatest number of perceived contributions to attainment of SDG targets. Many of these perceived contributions were linked to targets under SDG 14 (Life Below Water) and SDG 15 (Life on Land) for the direct protection of species and the environment. A significant number were also thought to contribute to six other SDGs ranging from No Poverty (SDG1) to Sustainable Cities (SDG11). In many ecosystem service frameworks, biodiversity is often not considered an service *sensu stricto* (Naeem et al. 2002), but rather the interactions amongst species and their environment are the means by which other ecosystem services are produced (Balvanera et al. 2006, Cardinale et al. 2012, Duncan et al. 2015, Ricketts et al. 2015). There is growing evidence that greater levels of biodiversity support enhanced and/or more stable provision of other services (e.g. insect diversity – pollination, Garibaldi et al. 2013; crop diversity – yield, Smith et al. 2008; tree diversity – carbon storage, Poorter et al. 2015). Where species conservation was not the primary objective of the SDG target, we expect that many of the contributions from habitat & biodiversity maintenance identified by experts to these latter goals were perceived as indirect in nature.

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

4.6 Survey limitations

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

This sampling approach may explain why certain ES-T combinations were evaluated much more frequently than others, resulting in under-evaluation of certain sets of ecosystem services or goals. For example, a large body of literature exists on the role of nutrient cycling and erosion control on downstream coastal water quality (Barbier 2012, Carpenter et al. 1998, Vitousek et al. 1997). However, the contribution of these services to SDG14.1 to *prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution,* was evaluated as having 'Weak' support because it was assessed by less than 5 respondents and only 5% of our respondent pool worked on coastal and marine systems (SM5). Thus, we urge a strong degree of caution before excluding the possibility of ES-T combinations not classified as having 'Strong' support, as they are highly susceptible to under-evaluation due to sampling bias. Additional research and review of current literature is needed on these linkages to broaden and better evaluate the evidence base for the potential contribution of these ecosystem services to SDG targets.

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

4.7 Ways forward

We recognize that ecosystem service management alone will be insufficient to achieve the ambitious SDG agenda. Ecosystem service management will need to be paired with complementary technologies and socio-institutional-based solutions in order to achieve targets over the short SDG timespan (2015-2030). For example, achieving clean water targets under SDG6 will require a combination of installing water treatment plants alongside catchment land cover and land use management. Similarly, efforts to eradicate malaria and other emerging neotropical diseases (SDG3 target 3.3) will require a suite of tools from land cover and land-use management for pest and disease control, to insecticide-treated bed nets and national health programs to educate and treat affected communities. In many instances socio-institutional solutions may offer cheaper and quicker solutions to pressing challenges, as they require less infrastructure to implement and can tackle some of the root causes of the problem (Cartwright et al. 2013). However, all too often ecosystem services are undervalued in planning which can lead to ineffective solution in the long term, e.g. levying of the Mississippi river to prevent flooding altered the hydrology sustaining the surrounding wetlands needed to buffer the coastline against storm surges (Day et al. 2007). Both socio-institutional and technology-based solutions should be planned in concert rather than in competition with ecosystem-based approaches at the outset of policy development to identify the most effective and enduring solutions to achieve national development aims while avoiding unforeseen trade-offs with other goals.

To facilitate uptake of ecosystem service-based approaches for the SDGs, new output indicators that speak directly to the metrics tracked in the SDG framework would be useful (Ferrier et al. 2016). Indicators which report ecosystem service outcomes in terms of land area or number of people affected (as is done in WaterWorld and Co$tingNature), malnutrition rates, and proportion of demographic groups with access to specific resources are likely more intuitive and compelling for decision-makers than traditional biophysical or economic indicators (e.g. tons of carbon, m^3 of water, avoided costs). Small changes to current model outputs, for example translating sediment erosion into avoided degradation or crop production into calories and micronutrient availability, are possible and would provide entry points with policymakers on the value of ecosystem service-based approaches. However, including these “human well-being” indicators in model outputs adds another ‘step’ in the chain of estimation from ecosystem function, service supply, and service use to human well-being, requiring greater model simplification and potentially increasing uncertainty and errors.

5. Conclusions

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

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8. Tables and Captions

Table 1. Sustainable Development Goals and the selected targets evaluated in the expert survey (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, 14.14,14.5, 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

Table 2. The 16 ecosystem services included in the expert survey modified from the original 22 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	

Table 3. Review of the output metric capacities of selected landscape level ecosystem service modelling tools.

Ecosystem Service Category	**Provisioning Services**			**Regulating Services**									**Supporting Services**	**Cultural Services**			
Modelling Tools	Food*	Raw Materials	Water**	Carbon Storage & Seq.	Moderation of Extremes	Water Reg.	Nutrient Cycling	Erosion Cont.	Water Quality	Pest & Disease Control	Air Quality	Pollination	Habitat & Biodiversity	Cultural & Spiritual	Recreat. & Tour.	Aesthetic	**Ease of Use**
Ecosystem Service Models																	
ARIES	■	■	■	■	■	■		■	■		■		■	■	■	■	Low
BLOSM	■	■					■	■	■								Mod
ClimSAVE	■		■	■		■				■			■	■		■	High
Co$ting Nature V2	■		■	■	■	■		■	■				■		■		Mod
InVEST	■	■	■	■	■	■	■	■	■			■	■		■	■	Mod
LandscapeIMAGES	■						■						■	■		■	Mod
OPAL			■	■			■	■									Mod
RIOS			■	■			■	■	■								Mod
SERVES	■	■		■					■			■	■		■	■	High
SolvES			■	■				■					■	■	■	■	High
UFORE/ i-Tree			■	■	■	■	■		■		■		■			■	High
WHBET†													■	■	■	■	High
Ecosystem Process Models																	
AnnAGNP			■				■		■								Mod
APEX	■	■	■	■		■	■	■	■	■							Low
CENTURY	■	■	■	■			■										Low
Kineros2			■			■		■	■								Mod
SWAT	■		■	■		■	■	■	■								Low
TEM	■	■	■	■			■										Mod
VIC			■	■				■									Mod
WaterWorld	■		■			■		■	■								High
Integrated Assessment Models																	
GLOBIOM	■	■	■	■			■						■				Low

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