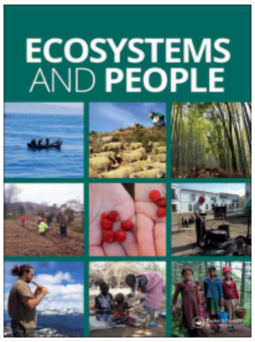

Ecosystems and People

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tbsm22

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To cite this article: Megan Meacham, Albert V. Norström, Garry D. Peterson, Erik Andersson, Elena M. Bennett, Reinette (Oonsie) Biggs, Emilie Crouzat, Anna F. Cord, Elin Enfors, María R. Felipe-Lucia, Joern Fischer, Maike Hamann, Jan Hanspach, Christina Hicks, Sander Jacobs, Sandra Lavorel, Bruno Locatelli, Berta Martín-López, Tobias Plieninger & Cibele Queiroz (2022) Advancing research on ecosystem service bundles for comparative assessments and synthesis, Ecosystems and People, 18:1, 99-111, DOI: 10.1080/26395916.2022.2032356

To link to this article: https://doi.org/10.1080/26395916.2022.2032356

ECOSYSTEMS AND PEOPLE
2022, VOL. 18, NO. 1, 99–111
https://doi.org/10.1080/26395916.2022.2032356

RESEARCH: TEN YEARS OF THE PROGRAM ON ECOSYSTEM CHANGE AND SOCIETY

Advancing research on ecosystem service bundles for comparative assessments and synthesis

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ABSTRACT
Social-ecological interactions have been shown to generate interrelated and reoccurring sets of ecosystem services, also known as ecosystem service bundles. Given the potential utility of the bundles concept, along with the recent surge in interest it is timely to reflect on the concept, its current use and potential for the future. Based on our ecosystem service bundle experience, expertise, and ecosystem service bundle analyses, we have found critical elements for advancing the utility of ecosystem service bundle concept and deepening its impact in the future. In this paper we 1) examine the different conceptualizations of the ecosystem service bundle concept; 2) show the range of benefits of using a bundles approach; 3) explore key issues for improving research on ecosystem service bundles, including indicators, scale, and drivers and relationships between ecosystem services; and 4) outline priorities for the future by facilitating comparisons of ecosystem service bundle research.

ARTICLE HISTORY
Received 14 September 2020
Accepted 17 January 2022

EDITED BY
Odirilwe Selomane

KEYWORDS
Ecosystem services; indicators; scale; drivers; multifunctionality

1. Introduction

There is growing recognition that actions to ensure and enhance the supply of multiple ecosystem services are urgently needed at local, regional and global scales (Bennett et al. 2015; Rieb et al. 2017; IPBES 2019). A range of global policy fora, agencies and international bodies are looking for ways to operationalize ecosystem services and account for nature's contributions to people within regulatory frameworks and daily practices (Allison and Brown 2017). For example, the European Commission's EU Biodiversity Strategy 2030 places a high priority on ensuring a sustainable supply of multiple ecosystem services (European Commission 2020). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES; http://www.ipbes.net/about-us) has synthesized the state of knowledge about how nature contributes to people, which ecosystem services are provided, to whom, and with what implications (IPBES 2019). Countries like Sweden (Khoshkar et al. 2020), Spain (Santos-Martín et al. 2016), France (Crouzat et al. 2019), Greece (Dimopoulos et al. 2017), United Kingdom (Albon et al. 2014), and more (Schröter et al. 2016) have developed national ecosystem assessment strategies. All these initiatives show an increased recognition that reliable, accurate assessments of multiple ecosystem services and nature's contributions to people are needed.

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Supplemental data for this article can be accessed here.

The majority of research assessing ecosystem services has focused on single or narrow sets of ecosystem services (Seppelt et al. 2011; Saidi and Spray 2018; Hölting et al. 2019). Assessments has also tended to focus on either ecological or social aspects (Abson et al. 2014). For example, ecological aspects have included evaluations of how different components of biodiversity help to generate various ecosystem services (Cardinale et al. 2012; Mace et al. 2012; Lavorel 2013) and spatially explicit mapping exercises of ecosystem services (Burkhard et al. 2012; Maes et al. 2012; Burkhard and Maes 2017). Social aspects have included the monetary or non-monetary valuation of ecosystem services (Pascual et al. 2010; Gómez-Baggethun and Ruiz-Pérez 2011; Arias-Arévalo et al. 2017; Christie et al. 2019; Lau et al. 2019), studies of the implications of ecosystem services for human wellbeing (Haines-Young and Potschin 2010; Polishchuk and Rauschmayer 2012; Fisher et al. 2014; Costanza et al. 2016; Kosanic and Petzold 2020) as well as how caring for nature and relational values shape the assessment of ecosystem services (Chan et al. 2016; Himes and Muraca 2018; Jax et al. 2018). However, ecosystem services emerge from the complex interactions between the social and ecological components of tightly coupled social-ecological systems (Reyers et al. 2013; Andersson et al. 2015, 2021; Folke et al. 2016). The social and ecological links are not marginal or temporary; they are intertwined, and in fact coevolving, shaping and being shaped by one another (Folke et al. 2016). People live in and relate to nature in many ways – as a source of resources, satisfaction, identity, and culture – and they manage and use their environment for a multiplicity of purposes (Chan et al. 2016). The Millennium Ecosystem Assessment played a significant role in fostering and mainstreaming such a social-ecological approach to humans and nature (e.g. Carpenter et al. 2009). IPBES further emphasizes the feedback between nature, ecosystem goods and services and human wellbeing with particular work on anthropogenic assets, institutions, governance, and direct and indirect drivers (Díaz et al. 2015). Specific social or land use management systems generate interrelated sets of ecosystem services. For example, farmers create agro-ecosystems that supply a set of ecosystem services, and governments establish national parks which provide a different set of ecosystem services. When these sets of ecosystem services are found to be recurring, they can be described as ecosystem service bundles (Raudsepp-Hearne et al. 2010; Martín-López et al. 2012; Hamann et al. 2015; Queiroz et al. 2015).

There is an important opportunity for providing policy-relevant insights given the increasing number of ecosystem service bundle assessments and the increasing awareness and investment in ecosystem assessments. Synthesizing and learning across ecosystem service bundle assessments is necessary for furthering our understanding of social-ecological dynamics, how they are expressed in the landscape and received by people. However, there are many hurdles to comparing assessments including differences in contexts, data, ecosystem services targeted, and original assessment goals. To advance the utility of ecosystem service bundle concept and deepen its impact in the future we 1) examine the different conceptualizations of the ecosystem service bundle concept; 2) show the benefits of using a bundles approach; 3) explore key issues for improving research on ecosystem service bundles; and 4) outline priorities for the future by facilitating comparisons of ecosystem service bundle research.

2. Approach

This paper is an outcome of the Programme on Ecosystem Change and Society (PECS; pecs-science.org) working group on the social-ecological dynamics of ecosystem services. Three working group workshops were held between January 2015 and August 2017 in Stockholm, Sweden (see supplementary material). The aim of the workshops was to initiate comparison of different ecosystem service bundles case studies. Participants at these workshops (the authors of this paper) represented a selected group of 18 local to national case studies that had assessed ecosystem service bundles (see Table S1 in supplementary material). The case studies covered a broad range of social-ecological contexts. Each case was part of individual scientific projects with their own priorities, aims and funding. Each of the cases have produced scientific articles outlining their study area, research questions, methods and results. The published articles and quantitative data for each case were reviewed during the initial workshop. The challenges that emerged from the initial goal of comparing these cases created the foundation for the results presented in this paper.

We compared each case's definition of ecosystem service bundles. Different facets of ecosystem services were at focus within the cases. We used additional literature to explore the range of definitions of ecosystem services bundles being used. We distilled the diversity of definitions in the three conceptualizations of ecosystem service bundles presented in Section 3. Based on the experiences from our cases and outcomes published by other ecosystem service bundles analysis processes we found five specific benefits to using an ecosystem services bundles approach. We outline these in Section 4 and Figure 1. Three key issues emerged as particularly important for the analysis of ecosystem service bundles and facilitating their potential for comparison. These issues, presented in Section 5, developed during our comparison attempts and were complemented by further discussions in the wider literature. The strategies for executing comparison (Section 6) are insights drawn from the discussions of indicators, scale and drivers and relationships between ecosystem services presented here and built upon previously published theoretical frameworks.

3. Conceptualizing ecosystem service bundles

One emerging and increasingly common approach to assess multiple ecosystem services, which is sensitive to the social-ecological context, is to study them as recurring sets of ecosystem services or 'ecosystem service bundles', (Foley et al. 2005; MA 2005). Ecosystem service bundles have been conceptualized in different ways, in order to capture the (1) supply of ecosystem services, (2) use of services by stakeholders, and (3) social preferences for ecosystem services. The prevailing approach is supply-based, which develops bundles from the observable recurring sets of ecosystem services supplied (or produced) across a given landscape or seascape (e.g. Raudsepp-Hearne et al. 2010; Qiu and Turner 2013; Hanspach et al. 2014; Queiroz et al. 2015; Yang et al. 2015). However, this more biophysical approach may not consider the people present in the landscape, and how their needs and actions relate to ecosystem services. The second approach to ecosystem service bundle assessments focuses on the sets of ecosystem services used by people in a given area (e.g. Hamann et al. 2015; Plieninger et al. 2019). This approach bridges both the ecosystem services provided in a landscape and the delivery of services to people there but may be limited to the ecosystem services that are known and reported by people. It also may not assess services that are desired but not available. The third approach to bundle assessments has therefore explicitly focused on the sets of ecosystem services preferred by different stakeholder groups (Martín-López et al. 2012; Plieninger et al. 2012; Hicks and Cinner 2014). However, preferences may be less directly linked to ecological capacity. Recent studies have attempted to assess the supply-based ecosystem service bundles and preference-based ecosystem service bundles and compare the mismatches in order to target management interventions (Baró et al. 2017; Quintas-Soriano et al. 2019).

4. Benefits of a bundles approach

There are many research objectives where an ecosystem service bundles approach may be appropriate. Expanding on categorizations by Saidi and Spray (2018), these objectives include: exploring ecosystem service patterns, identifying social-ecological systems, informing landscape management, studying the outcomes of land-use decisions, understanding land-use change over time, linking policy spheres and considering the role of local institutions in management. Although a range of methods could be used to advance these goals, there are particular benefits to using an ecosystem service bundles approach as summarized in Figure 1. Five main benefits provided by using bundle analysis are 1. simplifying analysis, providing an accessible analysis strategy that retains system complexity; 2. simplifying management, focusing on the interconnected nature of ecosystem services; 3. further developing practical social-ecological theory; 4. filling in data gaps, guiding reasonable assumptions that can be made when no other information is available; and 5. acting as a bridging tool, bringing divergent groups together.

In recognition of different needs, context and logistics, the design and execution of a bundles assessment will need to vary across cases (Andersson et al. 2021). As this study shows, the bundles approach together with a clear framework for positioning studies tailored to different research questions and local needs may help build a stronger foundation for comparison and for making cross case connections.

5. Key issues for improving research on ecosystem service bundles

5.1. Social-ecological indicators

A proliferation of ecosystem service indicators has emerged, as the concept increasingly takes center stage in the sustainability science and policy arenas (Egoh et al. 2007; Layke et al. 2012; Díaz et al. 2015). Consequently, the indicators used for assessing different ecosystem services vary greatly among studies of ecosystem service bundles, in particular if studies differ in their conceptualization of ecosystem service bundles as discussed in Section 3 (Figure 2). Indicators used will also vary across studies because of differences in focal research questions, available methods, and ease of measurement.

The more biophysical or nature-based indicators measure ecosystem service potential production. They are focused on the current capacity of a particular ecosystem to supply a given ecosystem service (Burkhard et al. 2012, Crouzat et al. 2015). Indicators of nature's actual benefits to people are the ecosystem services used. These types of ecosystem service indicators capture how much of the ecosystem service is received by people and is often measured directly as the amount of a service delivered, or indirectly as the numbers of beneficiaries served (Hamann et al. 2015). Indicators that measure people's perceived value, demand, need or preference for

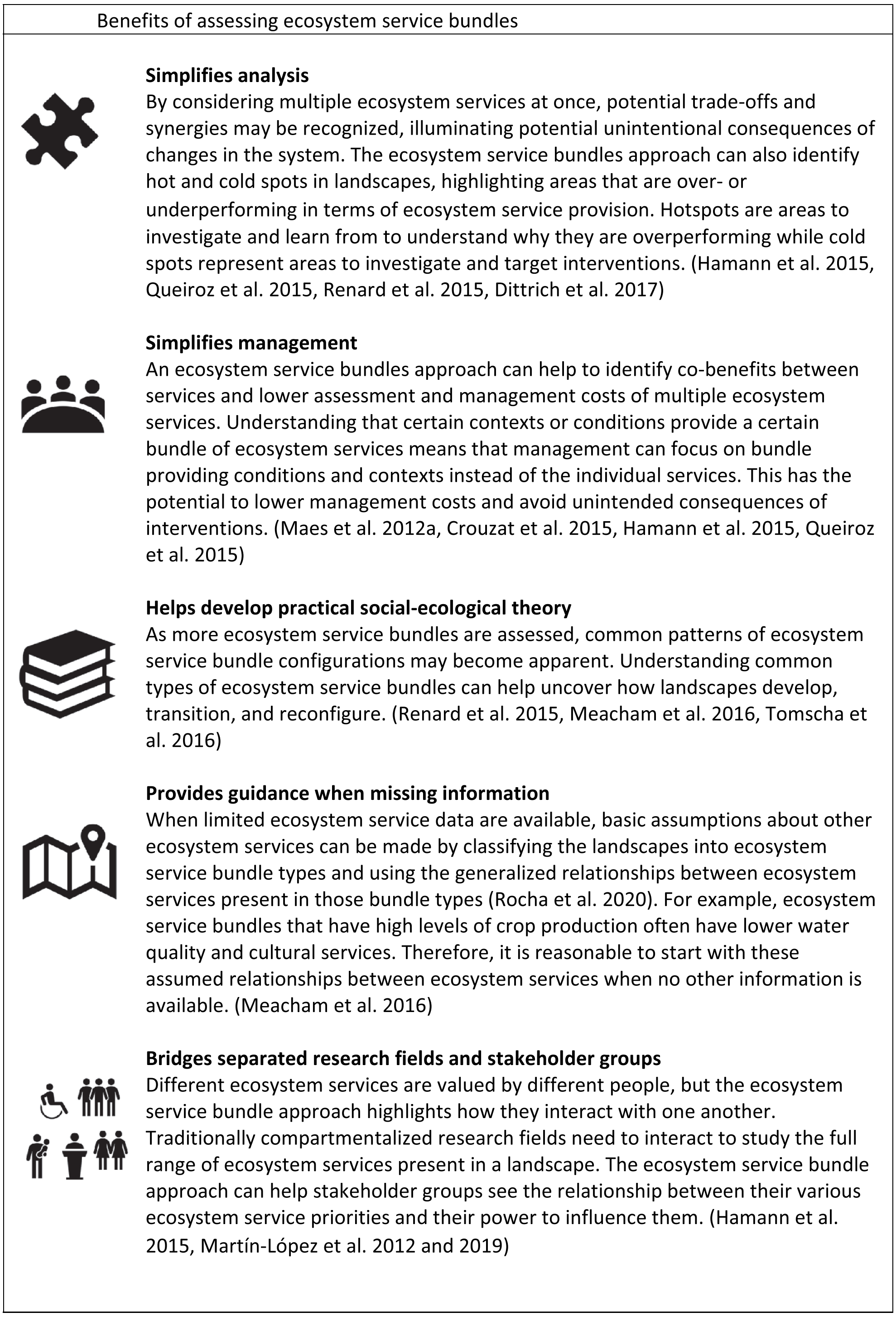

Figure 1. Benefits of assessing ecosystem service bundles.

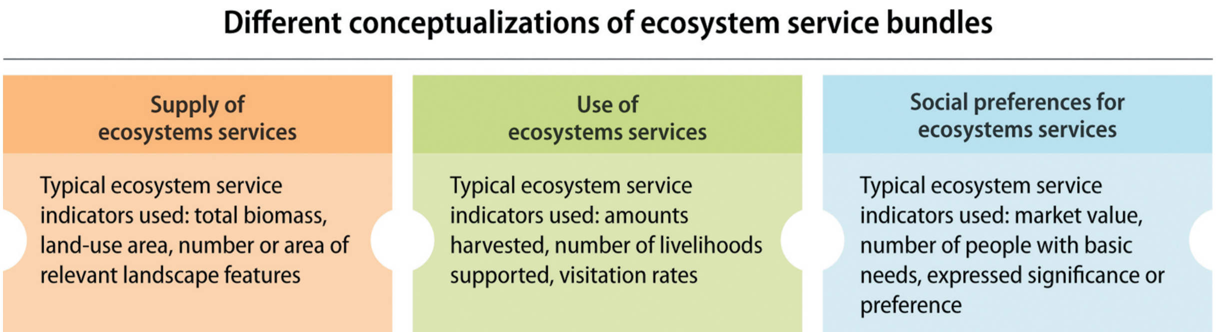

Figure 2. Ecosystem services indicators represent different aspects of the relationship between people and their environment.

a given ecosystem service represent links to human wellbeing (Martín-López et al. 2012).

The types of indicators used in assessing ecosystem service bundles are not necessarily restricted to the dimensions that best represent the conceptualization of bundles being used, but instead are determined by many factors including data availability, methods used, research questions, and which specific ecosystem services are assessed. For example, regulating services (like carbon sequestration) are often assessed through nature-based indicators (e.g. via models like InVEST (Sharp et al. 2020)), even in assessments that are primarily preference-focused. Cultural services, such as recreation or aesthetic value, are often measured using indicators related to their use and value (e.g. derived from social media data (Zhang et al. 2020)). Some assessments of ecosystem service bundles have used a mix of types of indicators (e.g. Queiroz et al. 2015) and some have used indicators from a single dimension (e.g. Hicks and Cinner 2014; Hamann et al. 2015) (Table S1).

The interpretation and potential policy recommendations derived from an ecosystem service bundle analysis should be consistent with the types of indicators used. For example, ecosystem service bundles derived from nature-based indicators will reflect the potential production of ecosystem services. However, without verifying the actual ecosystem service use and value in the system, policy decisions could have unintentional results. On the other hand, using explicitly ecosystem service value indicators may draw attention to conflicting needs of resource users, but will not properly capture the ecological and biophysical constraints of the landscape in generating that set of ecosystem services.

The level of commensurability between different types of indicators can vary based on the social-ecological context of the study. In many regions (often traditionally managed multifunctional landscapes), the benefits flowing from ecosystem services are experienced locally, and local people are more likely to be in charge of landscape management (e.g. Hartel et al. 2014). In such cases, it is reasonable to assume that the landscape, to a large extent, reflects the priorities and needs of the people living there. In this case, the production of ecosystem services is coupled to the use and value and assessing one type of ecosystem service indicator can inform the others. However, in a landscape where the people living there have limited influence over the development and management of the landscape, what is produced there may not reflect what is needed or valued by the local population. This is often the case in monofunctional production landscapes that are optimized for one or a few particular crops. In these landscapes, few local people are involved in making decisions about the ecosystem services produced and the benefits flow to a small set of privileged actors or are exported (Riechers et al. 2020). The resulting ecosystem service bundles in this case will be quite different if nature-based indicators are used versus using preference-based indicators.

In summary, when assessing ecosystem service bundles, it is important to reflect on what the ecosystem service indicators chosen actually represent, and how they should be interpreted for decision-making and management purposes. Understanding the social-ecological context of the landscape being assessed, can help clarify the relationships between ecosystem service supply, use and value within the given case study. Such a social-ecological approach, which integrates social and ecological factors in the generation and delivery of ecosystem services, can help develop better targets, policy objectives, and ecosystem service indicators (Reyers et al. 2013; Meacham et al. 2016).

5.2. Scale – extent, grain and units of analysis

Assessments of ecosystem service bundles are carried out at different spatial extents and focus on different types of units. The ecosystem service patterns detected in ecosystem service bundle assessments will ultimately be a function of spatial scale. Scale has two important dimensions: extent and grain (or units of analysis). Extent is the overall area encompassed by an investigation or the area included within the landscape boundary. Grain is the size of the individual units of analysis. The choice of units of analysis and the spatial extent of a study are clearly related to one another. The spatial extent sets the upper limits for reasonable grain size, and similarly with an increasing extent usually increases grain size for reasons of feasibility. Consequently, the extent and grain are often correlated (i.e. studies that cover large areas tend to have larger grain sizes).

The spatial extent of studies addressing ecosystem service bundles in social-ecological systems is often determined by data availability. At the same time, many studies focus on landscape and regional spatial scales, with their spatial extent spanning hundreds to thousands of square kilometers (Saidi and Spray 2018), because it is often at these scales that policy is implemented. These larger extents also often represent institutional, social and physical spaces that are tangible and meaningful for humans (Hein et al. 2006; Scholes et al. 2013). A minority of studies have been conducted at national (Turner et al. 2014; Dittrich et al. 2017) or multinational (Maes et al. 2012) scales capturing a diversity of landscapes and social-ecological systems.

A broad range of different units of analysis have been used in studies that assess ecosystem service bundles. The majority of studies divide landscapes into a large number of spatial units. These spatial units can be regularly shaped and evenly distributed, such as in a raster or grid (e.g. Turner et al. 2014). Uniform grids can in some cases be better suited for spatial analyses because of the consistency in area among the units of analysis. Spatial units can also be irregularly shaped, following biophysical features or administrative features, such as watersheds or municipalities, respectively (e.g. Queiroz et al. 2015; Odgaard et al. 2017). Municipalities and villages are often chosen because they are the smallest scales at which many decisions regarding planning and landscape management are made – decisions that directly affect ecosystem services. A combination of both biophysical and administrative features is also possible (e.g. Hanspach et al. 2014). An alternative to a spatial unit of analysis is a social unit, i.e. representing different levels of social aggregation. Social units that have been used include the individual (e.g. Martín-López et al. 2012), households (e.g. Dorresteijn et al. 2017), user groups (e.g. Milcu et al. 2013) or communities (e.g. Hicks and Cinner 2014).

Using social or spatial units can generate very different patterns of ecosystem service bundles, because they aggregate ecosystem services in distinct fashions. For example, Martín-López et al. (2012) assessed ecosystem service bundles as the suites of ecosystem services that individuals belonging to various stakeholder groups prefer. They showed that urban and rural people have preferences for different sets of services. However, these services may all be produced in the same place. Therefore, a single location may have multiple ecosystem service bundles associated with it when people's preferences are defining the ecosystem service bundles. On the other hand, when spatial units are used, each location will only have one ecosystem service bundle associated with it.

Ecosystem services are created by a variety of social-ecological processes and structures that operate across distinct spatial scales (Anderson et al. 2009; Spake et al. 2017). For example, the extent of a study will influence the diversity of ecological processes and types of ecosystems falling within the study area and a study with a small extent might describe the trade-offs within one ecosystem (Hicks and Cinner 2014) as opposed to patterns over many different ecosystems (Jopke et al. 2015). Furthermore, interactions between some ecosystem services, and thus the ecosystem service bundles generated, may be observable at some scales and not others. The relationship between food production and water quality has been shown to vary greatly across scales (Qiu et al. 2018). Some recent studies (Raudsepp-Hearne and Peterson 2016; Qiu et al. 2018) systematically investigated how ecosystem services are produced, used and managed at different scales and how these matter for ecosystem service bundles assessments. By analyzing how the scale of analysis affects results by mapping services at three different spatial scales, Raudsepp-Hearne and Peterson (2016) demonstrated that although there is consistency in trade-offs and synergies among ecosystem services across scales, changes in the scale of analysis alter the bundles of ecosystem services that are identified in a landscape.

In summary, many factors determine the scale of the ecosystem service bundle assessment, including the resolution of the data available (e.g. socioeconomic census data), the demands of decision makers, and the physical characteristics of the region. The amount of variation (heterogeneity vs homogeneity) of the social-ecological systems will strongly influence the effort needed to detect bundles. Each study of ecosystem service bundles has to balance what ecosystem services are assessed, the number of ecosystem services assessed, and the social and ecological variation present (Raudsepp-Hearne and Peterson 2016). More units are necessary to detect patterns of ecosystem services when there is limited spatial variation, for example. How sensitive the ecosystem service bundle is to the scale assessed depends on how patchily or evenly distributed the types of services included are. For example, while wild berry collection and hunting might be patchy, crop production and forest recreation are often evenly distributed across the landscape. Transparency about these constraints and decisions will help to contextualize the assessment and make it more relatable and replicable.

5.3. Drivers and relationships between ecosystem services

To understand how ecosystem service bundles will persist or evolve in the future, it is important to explore the factors shaping their configurations. Bennett et al. (2009) designate two factors affecting the development of ecosystem service bundles: 1) internal relationships between ecosystem services, and 2) external drivers affecting one or more ecosystem services or their relationships.

Often, maps and correlations across space are used to look for ecosystem service bundles and assume relationships between ecosystem services. However, the observation that specific services occur together does not automatically explain why they are co-occurring. Lavorel and Grigulis (2012) showed how the functional constraints of organisms determine true relationships between ecosystem services. Qui et al. (2018) found that the relationships between ecosystem services changed based on biophysical connection, scale effects, and effects from dominant drivers. Felipe-Lucia et al. (2014), Felipe-Lucia et al. (2018) distinguish between three types of interactions: interactions due to management decisions, environmental factors or intrinsic ecological factors.

Considerably more research has focused on the effect of drivers (Bennett et al. 2009; Rounsevell et al. 2010; Robards et al. 2011; Meacham et al. 2016). Drivers are external factors that affect the configuration of an ecosystem service bundle. Drivers often, but not necessarily, reflect human management or intervention. Common examples of drivers include the application of fertilizer to agricultural fields, afforestation, designating legally protected conservation areas, climate change, and population growth (MA. Millennium Ecosystem Assessment 2005; IPBES 2016). Drivers can affect one or more ecosystem services and at the same time may have an amplifying effect for some ecosystem services and a dampening effect on others. For example, a commonly identified ecosystem service bundle across different agricultural landscapes is a bundle characterized by strong negative trade-offs between provisioning agricultural services and regulating services (Raudsepp-Hearne et al. 2010, Felipe-Lucia et al. 2022). This trade-off is primarily due to drivers such as increased fertilizer use which simultaneously affect crop yields and water quality. Some drivers of ecosystem service bundles are more commonly studied: land use change (Lambin et al. 2001; Foley et al. 2005; Metzger et al. 2006; Locatelli et al. 2017), human population growth (Eigenbrod et al. 2011), Gross Domestic Product and other large scale coarse economic variables (He et al. 2014), climate change (Schröter et al. 2005) and their interactions within scenarios (Harrison et al. 2015; Mouchet et al. 2017). Other drivers, especially those that reflect social-ecological dynamics, may be important, but are typically less studied (i.e. power dynamics and value change), but see Chan et al. (2012), Felipe-Lucia et al. (2015) and Martín-López et al. (2019) for some examples.

Exploring why ecosystem service bundles are structured a given way will help to show how the ecosystem service bundles may evolve and transform through time and across space. Most current assessments of ecosystem service bundles are a snapshot in time, only revealing the current state of ecosystem service production, use or preferences. However, a few studies have taken a historical approach, investigating how ecosystem service bundles have changed through time and how relationships between ecosystem service bundles and key drivers have changed (Renard et al. 2015; Tomscha et al. 2016; Lavorel et al. 2017; Locatelli et al. 2017; Santos-Martín et al. 2019). The historical context of a given region will help to explain how stable an ecosystem service bundle is; how consistent the relationships between the ecosystem services are and how likely an ecosystem bundle will persist into the future (Renard et al. 2015; Dittrich et al. 2017; Lavorel et al. 2017).

In summary, measuring and reporting a common set of drivers alongside the ecosystem service bundle assessment will provide context and help facilitate and strengthen comparisons. Information on social, ecological and geographic drivers are often available in even data-poor regions. For example, education levels, age, population density, income, land cover types, altitude, slope, and distance from a city may be available. Considering how ecosystem service bundles may change in the future can be explored by looking both at the past and the future. Considering the future trajectory of the region will emphasize which drivers and their effects may be dominating in the future. Information on stated planning goals, development targets and aspirational visions for the future of the region will highlight management and investment priorities (e.g. Palomo et al. 2011; Hanspach et al. 2014).

6. Comparisons of ecosystem service bundle research

There is an untapped potential for policy relevance by synthesizing and learning across research on ecosystem service bundle assessments. There are many relevant questions that comparisons can help answer: How do different ecosystem services interact and co-vary under different management and governance practices? How are benefits from ecosystem services distributed between groups of people? Are there shared types of bundles of ecosystem services found across case studies, and are these typologies of social-ecological systems? What explains the differences among these types of bundles – what are the key ecological, social, and geographic drivers to explain patterns of ecosystem services and ecosystem service bundles across cases? Do geographic, social, or ecological factors dominate? Are there shared drivers across sites? However, individual assessments not only differ in their conceptualization of ecosystem service bundles but are also carried out in different contexts, include different numbers and types of ecosystem services, and are not originally performed with the intention to compare.

6.1 Types of comparisons

Using the framework developed by Kronenberg and Andersson (2019) regarding the possible combination of different valuation methods, we consider the comparability of ecosystem service bundles studies along two axes, commensurability and compatibility (Figure 3). Commensurability refers to the underlying research perspective of the study, specifically the different conceptualizations of ecosystem service bundles from Section 3. For example, two ecosystem service bundle assessments

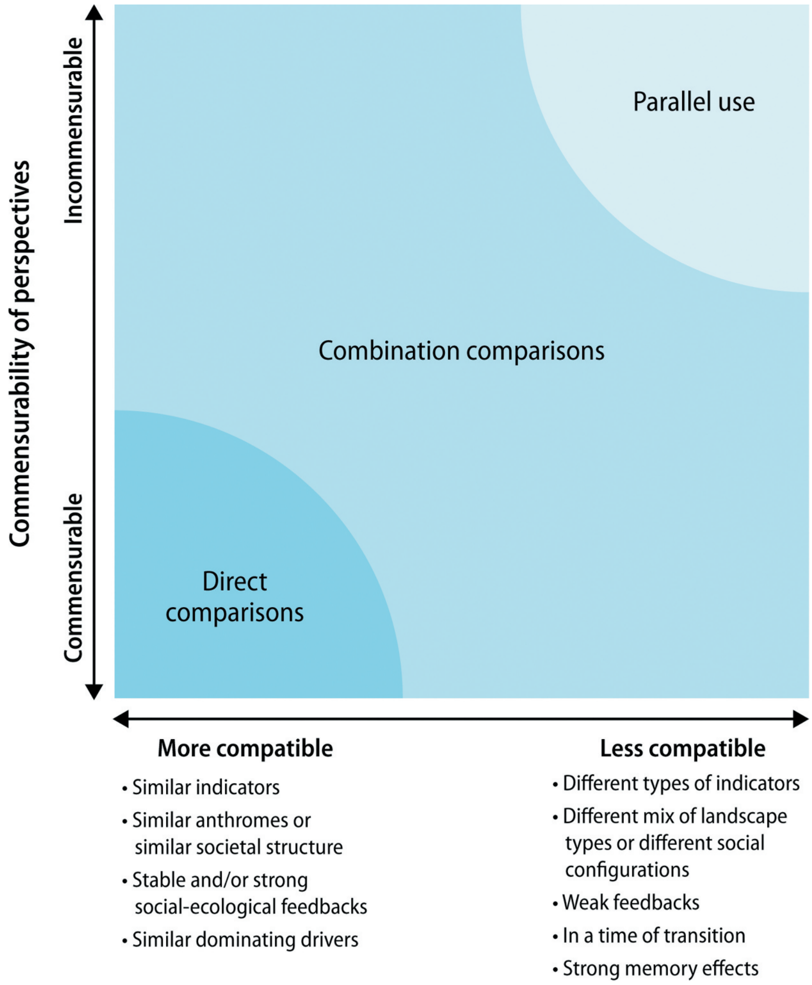

Figure 3. Comparability of ecosystem service bundle studies Three types of comparisons are possible (direct comparisons, combination comparisons, and parallel use) based on the commensurability of conceptualization of ecosystem services bundles taken by each study and the compatibility of the indicators, scales and methods used. The figure is adapted from Kronenberg and Andersson (2019).

that both define bundles as the sets of ecosystem services preferred by different stakeholder groups would be commensurable because they use the same definition of bundles. Compatibility is the degree to which the technical aspects of the study align. The underlying data, types of units analyzed, and scale used can range from identical to incompatible with a gradient in between. Depending on the levels of commensurability and compatibility comparisons will serve different purposes. In Figure 3 we illustrate three types of comparisons, direct comparisons, combination comparisons, and parallel use.

When the methods of the studies to be compared are fully commensurable and compatible direct comparisons are possible. The second level of comparability is when studies are not fully commensurable or compatible. These combination comparisons are useful for providing further perspective and context. For example, a study of ecosystem service bundles in southern Spain compared spatially defined bundles to bundles defined by people's preferences to find mismatches and opportunities for interventions (Quintas-Soriano et al. 2019). Comparing studies with the same conceptualization of ecosystem service bundles, but from different contexts or using different types of data can be useful in exploring generalizable patterns. Comparisons between studies that are incompatible and incommensurable (parallel use) play an important role in contributing to the overall understanding of social-ecological systems. This parallel use of studies is a way to triangulate research methods by situating studies in the broader ecosystem service bundles field.

6.2. Finding areas of compatibility

In most cases, ecosystem service bundles studies have their own priorities, research questions, methods, local contexts, and practical constraints that ensure some level of incompatibility and incommensurability with any other study. However, several strategies can help with comparisons. Describing the studies to be compared by the elements that can form or constrain compatibility will help highlight the areas of commonality. Figure 3 highlights the factors that contribute to or detract from compatibility.

Synthesis and comparisons across ecosystem service bundle case-studies will be expedited if the same types of ecosystem service indicators are used. However, if the ecosystem service indicators are different, then an understanding of the relationship between the supply, use and value of the ecosystem services is needed. Differences in ecosystem service indicators used can also be compensated for when the cases have similarities in their social or ecological contexts. Similar demographics, development trends, historical legacies, land use types, and heterogeneity could anchor comparisons between ecosystem service bundle analyses that potentially have differing ecosystem service indicator types.

The types of ecosystem services assessed in the ecosystem service bundle assessment will determine how sensitive the ecosystem service bundles are to differences in scale. Ecosystem services that are evenly distributed across large spatial scales and often associated with extensive land cover categories (e.g. crop production and forest recreation) will behave more consistently across case studies that employ different spatial extents and grain. In contrast, ecosystem service bundle assessments that are predominantly composed of cultural and provisioning ecosystem services not associated with extensive land covers may not be as consistent across scales. For example, wild berries or hunting, are types of ecosystem services that will likely have unpredictable and very patchy distributions across the landscape. Ecosystem services that are dependent on people's access to the particular landscape elements, e.g. recreation, may also occur in patchy distributions that may not be detected when larger scales of observation are used. These types of services may also have limited representation in ecosystem service bundles that are strongly driven by main land cover types (Mouchet et al. 2017; Vannier et al. 2019).

Comparing across cases is one strategy for assessing true interactions between ecosystem services versus mere co-occurrence. Exploring which ecosystem services are most determinative in the bundling of ecosystem service helps explain the bundle's structure. Methods such as random forest analysis ranking, and hierarchical models have been used to rank ecosystem services in their importance in determining the ecosystem service bundle configuration (Meacham et al. 2016). Comparing ecosystem service bundle structures across cases is a way to circumvent other inconsistencies between cases and allow for an informative comparison.

Another opportunity for comparison despite differences in scale and units of analysis is to focus on the relationships between services revealed by the ecosystem service bundle analysis (i.e. the tradeoffs and synergies among services). Comparing the patterns of relationships of the ecosystem services within the bundles would provide useful insights into what kinds of ecosystem service interactions are repeatedly observed and possibly generalizable. Qiu et al. (2021) compared the relationships between ecosystem services from four ecosystem service bundle studies and found that trade-offs between ecosystem services were consistent across the cases, but their magnitude was influenced by the land-use intensity within each case.

When common types of drivers are assessed across cases, comparisons of the influence of the drivers on the distributions of ecosystem services can bypass the issues with inconsistencies in ecosystem service indicator types and scale. Many cases report driver or co-variable data as a way to provide context. Using these variables, we can compare cases that are facing similar driver trends and study how their ecosystem service bundles are affected by this driver pressure.

7. Conclusion

In this paper we show that assessing ecosystem service bundles is an important research frontier and that such assessments can facilitate comparisons between case studies without blurring specificities. Assessing ecosystem services in relation to one another using the ecosystem service bundles perspective provides valuable insight into the multifunctionality of landscapes and the social-ecological co-production of ecosystem services. The ecosystem service bundles concept is evoked in a variety of ways to assess sets of ecosystem services that are at a minimum co-occurring. We outlined several strategic advantages to using an ecosystem service bundles approach. The key issues of indicators, scale, and drivers and relationships between ecosystem services are important avenues to understanding what is being studied, what is known, and what is generalizable. They each create challenges for the comparison of divergent studies, but also opportunities. Comparing cases is possible through finding points of compatibility in the indicators, scales, or social or ecological context. Comparisons can focus on the internal ecosystem service relationships and relationships with drivers. The insights learned from comparisons and syntheses are needed for managing and sustaining the diversity of ecosystem services upon which we all depend.

Acknowledgments

This work was the collective efforts originated from three workshops from 2015-2017 on the social-ecological dynamics of ecosystem services that were financially supported by the Programme on Ecosystem Change and

Society (PECS) and took place in Stockholm, Sweden (FORMAS grant #SEEN to GP and AN). M.M. received support from the Marianne and Marcus Wallenberg Foundation (MMW 2017.0137). R.B. received support from the South African Research Chairs Initiative (SARChI) (grant 98766) and a Young Researchers Grant from the Vetenskapsrådet in Sweden (grant 621-2014-5137).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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