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Form follows function? Proposing a blueprint for ecosystem service assessments based on reviews and case studies

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A R T I C L E I N F O

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A B S T R A C T

Ecosystem service assessments (ESA) hold the promise of supporting the quantification and valuation of human appropriation of nature and its goods and services. The concept has taken flight with the number of studies published on the topic increasing rapidly. This development, and the variation of diverging approaches, support innovative ideas and may lead to complementary insights from various perspectives. However, at the same time this slows scientific synthesis through increasing uncertainty with respect to the appropriate methodologies to be used to support solving environmental management problems.

We analyzed ESA and the underlying concepts based on the variety of available publications and reviews, which revealed a number of different methods, uncertain reliability and robustness. In order to facilitate comparison, evaluation and synthesis of ecosystem service assessments we propose a blueprint for reporting studies in a structured way. By exemplifying this with worked examples, we argue that the use of such a blueprint will (i) assist in achieving improved communication and collaboration in trans-disciplinary teams; (ii) reveal methodological aspects, important for the interpretation of results; (iii) support robustness and reliability of assessments; (iv) aid in structuring assessment studies and monitoring programs; (v) provide a base for comparing and synthesizing results of different studies (e.g. in meta-analysis), and thus (vi) provide a base for further implementation of ESA.

1. Introduction

Ecosystems provide goods and services, which contribute to human well-being, and are referred to as ecosystem goods and services (Harrington et al., 2010; MA, 2005; Daily, 1997). They range from nutrient cycling and carbon sequestration to food production and recreational experiences (Carpenter et al., 2006). The concept aims at supporting instruments for the appropriate use of environmental goods and services. Ecosystems and the services they provide are under constant threat from human activities (CBD, 1992; Foley et al., 2005) which stresses ecosystems through the (over) utilization of their functions (Sagoff, 2011). Such threats materialize wherever the use of natural resources exceeds the capacity and resilience of the system to regenerate while maintaining its system identity, and thus its potential for future ecosystem service provision. The main reason for the overexploitation of ecosystem services is the mono-functional use and corresponding management of landscapes – still most frequently favored over

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multifunctional use (De Groot et al., 2010) – which maximizes one service at the expense of others. Through these actions, humans realize economic gains; however, the cost becomes decreased opportunities for humanity to enjoy a sustained well being for current as well as future generations.

Two basic problems appear: (i) costs and benefits of resource use are spread unevenly in space and time. This leads to situations where it is economically rational for certain stakeholder groups to use resources in an unsustainable way because it is likely that they will not experience the negative consequences of their behaviour (Ostrom, 2009); and (ii) it is not possible to maximize all ecosystem services simultaneously, and ecosystem management must aim to provide an optimal balance of services meeting the public's needs. One tool to this end is the valuation of ecosystem services.

Ecosystem service assessments (ESA) which quantify and value ecosystem services may contribute to decision making by clarifying the synergies and trade-offs that come from land and ecosystem management (Balmford et al., 2008; TEEB, 2010; Dasgupta, 2010). One result of the United Nations' Millennium Ecosystem Services Assessment (MA) process was its capacity to provide a framework for communication, i.e., its appeal as a metaphor (Norgaard, 2010). This paper goes beyond classification and description providing a metaphor for communication by suggesting a systematic approach to ESA through quantification and measurement. It stops short of providing non-monetary and monetary valuation methods for valuing certain aspects of ecosystems and their services, which are frequently suggested to express changes in natural processes and resources in a common monetary currency and thus giving a common platform for communication among stakeholders (Farley, 2008). The current popularity of ecosystem valuation, however, may have pushed aspects of the ecosystem services concept to the background, e.g. scientific base of ecosystem function and reproducibility of implementation actions (Carpenter et al., 2006; Fisher et al., 2008). Finally, economic valuation is just one aspect within the ecosystem service concept and not necessarily the adequate and optimum indicator or instrument for resource management.

Scientific studies to inform policy-makers abound (e.g. Rees, 2006; Spangenberg and Settele, 2010), but the science of ecosystem services may not be as readily developed (Holling, 2001; Ghazoul, 2007; NRCC, 2007; Kienast et al., 2009). It is important that future research utilize the ecosystem service approach to complement biodiversity focused conservation policy (Anton et al., 2010; Polasky and Segerson, 2009; Daily et al., 2009; Carpenter et al., 2009). The potential for a rapid escalation of research into ecosystem services emphasizes the need to set standards and guidelines for how the concept, and its terminology, are used.

Thus, there is a need for a consistent framework for ecosystem service assessments based on documenting data, utilizing empirically tested hypotheses, models, and reporting of results and recommendations as stated in the MA follow up process (Ash et al., 2010). The use and application of our proposed blueprint for studies in ecosystem service assessment can achieve an important objective: transparency and a clarification of structure and intentions. One might argue that this is somehow obvious and unnecessary to mention. One needs to be aware that the implementation of ESAs is rarely a strict scientific exercise. Thus, transparency, clarity, and structure of scientific input are essential for effective ESA.

Based on this recent discussion, we develop a state-of-the-art blueprint for documenting ecosystem service assessments. The blueprint aims at achieving two important objectives: firstly, from a scientific perspective we aim to provide a guideline which enables comparison between existing studies providing the potential to analyze complementarities between diverging assessments, and to conduct meta-analysis of assessment results. The second objective is to provide decision-makers, stakeholders and practitioners with a guideline for structuring their ESA.

2. State-of-the-art

Ecosystem service assessments are typically transdisciplinary, and focus on regions characterized by different spatial and temporal scales, often with more than one landscape type, and several ecosystems. Ecosystem services often go unrecognized in policies, markets, conservation and natural resource management practices. This occurs for a variety of reasons. In some cases the focus is exclusively on nature protection without taking services for humans into account. Politically, the concept is often too new to resonate with mainstream decision-makers. Additionally, resource managers and traditional economists work with production functions and do not include nature and its services. Among economists, monetization is disputed: while for instance Costanza et al. (1997), Daily et al. (2009) and TEEB (2010) suggest that monetization is a major step towards Ecosystem Services preservation, Vatn and Bromley (1994), Norgaard (2010) and Vatn (2010) suggest it is more appropriate not to define economic values. Different review papers on the concepts and methods of economic valuation of ecosystem services have discussed this issue (Bateman et al., 2010; Boyd and Banzhaf, 2007; Nunes and van den Bergh, 2001; Spangenberg and Settele, 2010) without producing a consensus yet.

Implementing policy decisions requires tools such as regulations, directives, plans, fees and other economic instruments; their choice and specification would benefit from a coherent base of transdisciplinary ESA. A number of directives and regulations such as the European Water Framework Directive (WFD; EC, 2000), the ecological network of special protected areas (NATURA, 2000; EC, 2008), the Integrated Coastal Zone Management ICZM (European Parliament and Council, 2002) in Europe and the Total Daily Maximum Load program (TDML; NRC, 2001) in the US emphasize integrated assessments and thus have posed significant challenges to managers, planning authorities, researchers and stakeholders (Jessel and Jacobs, 2005). These assessments: (i) focus on functional units rather than administrative boundaries; (ii) consider natural scientific as well as socioeconomic aspects; and (iii) emphasize stakeholder interactions (Arabi et al., 2007; Dilks and Freedman, 2004; Volk et al., 2009).

The demand for ecosystem service based instruments that support sustainable human appropriation of environmental resources is increasing at a greater pace than which scientists are able to provide robust information on ecosystem functioning – ecosystem services relationships. For example, *The Economics of Ecosystems and Biodiversity* (TEEB[1]) was "just" a complex, ambitious quantitative review study on the valuation of ecosystem services and biodiversity. However the World Bank's Global Partnership for Wealth Accounting and the Valuation of Ecosystem Services (WAVES[2]) initiative is much more ambitious, as it relies on appropriate tools for ecosystem service assessments for the accounting of EES including concepts such as the green GDP.

Recent publications, which aim at providing scientific support for implementing ecosystem services into practice, focus either on conceptual development or meta-analyses of ESA. Both aspects are of equal importance for the necessary design of a blueprint. The first aims at providing concepts and the latter at analysing the implementation of ESA (Boyd and Banzhaf, 2007; Ghazoul, 2007; Gómez-Baggethun et al., 2010; Luck et al., 2009; McCauley, 2006; Muradian et al., 2010; Armsworth et al., 2007). Second, ESA could also be organized along a gradient from application-oriented to scientifically focused papers. Thus, available studies can be mapped

[1] http://www.teebweb.org/.

[2] http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/0,contentMDK:22811907~pagePK:210058~piPK:210062~theSitePK:244381,00.html.

Table 1
Representation of publications cited in the paper and used for the development of the blueprint. The papers are sorted according to their methodology, data-based, meta-analysis versus theoretical, conceptual and their objective, providing methodological and conceptual guidance versus provisioning of application oriented guidance. Note, the majority of studies focus on conceptual and approaches; data-based studies and meta analysis are rare.

	Methodological approach	
Objective	Data-based analysis, Bottom-up approach: Analysis of multiple, place-based studies, meta-analysis	Conceptual development, Top-down approach
Scientific analysis, theory driven	Seppelt et al. (2011), Moberg and Folke (1999)	De Groot et al. (2002), Armsworth et al. (2007), Boyd and Banzhaf (2007), Ghazoul (2007), Fisher et al. (2008), Norberg (1999), Costanza (2008)
Application oriented	Goldman et al. (2008), Tallis et al. (2009), TEEB (2010), Muradian et al. (2010)	EES (2010)

simply in a 4-field-matrix (see Table 1). This framework is used for the development of our reporting blueprint.

Many schemes have been developed to define and communicate the ecosystem service concept with variations based on the intended application of the framework (e.g. valuation, assessment and/or management of the ecosystem services), area and scale of applicability, and definition of terms (Boyd and Banzhaf, 2007; Ghazoul, 2007; Armsworth et al., 2007; Fisher et al., 2008; De Groot et al., 2002; Kosoy and Corbera, 2010; Lamarque et al., in press). The central focus of assessments in the United Nations' MA (2005) framework is human well-being, which recognizes human dependency on the natural environment for the provision of environmental, social, and economic benefits. Several attempts have been made both to categorize and comprehensively list ecosystem services; yet, there is no present consensus on a useful taxonomy (Costanza, 2008; Fisher et al., 2008). Categorizations of ecosystem services differ as a result of the specific biophysical and socio-cultural context (Gómez-Baggethun et al., 2010) in which ecosystem services are being defined, leading to both strengths (e.g. individually tailored solutions) and weaknesses (e.g. lack of consistency of approach and hence difficulties in comparing between areas/projects and communicating results). Some categorizations are defined by:

– functional groupings, such as regulation, carrier, habitat, production, and information services (De Groot et al., 2002, 2010);
– organizational groupings, such as services that are associated with certain species, that regulate some exogenous input, or that are related to the organization of biotic entities (Norberg, 1999); and
– descriptive groupings, such as renewable resource goods, non-renewable resource goods, physical structure services, biotic services, biogeochemical services, information services, and social and cultural services, see Moberg and Folke (1999) as an example.

Besides synthesizing different conceptual work, information on the design and performance of ESA can be obtained by comparing reviews and recent meta-analysis on ecosystem service research, examples include Goldman et al. (2008), Tallis et al. (2009), Muradian et al. (2010) and Seppelt et al. (2011).

Goldman et al. (2008) and Tallis et al. (2009) used structured interviews with project coordinators of the Natural Capital Projects to demonstrate projects using the Ecosystem Service concept focused on the same threats as biodiversity and conservation projects. However, projects based on ESA were able to make use of a broader variety of revenue streams, use more instruments and mechanisms, and involve more landowners and stakeholders. Our analysis identified two important aspects as discussed by Goldman et al. (2008). Firstly, regional projects, management instruments, and strategies derived out of the ecosystem service concept are successful and possibly more flexible than simple conservation measures. Secondly, they also provide an excellent methodology for systematically characterizing the properties of such studies. Some of the elements of their structured interviews support the development of our blueprint, see Supplementary material in Goldman et al. (2008). Muradian et al. (2010) demonstrates that successful implementation of ESA based instruments requires a deviation from economic theory.

Seppelt et al. (2011) provided a quantitative review of 153 ecosystem service studies in scientific papers (ISI Web of Knowledge). The studies were characterized using a set of indicators; see Supplementary material of Seppelt et al. (2011). Recent studies show the ecosystem service concept is frequently applied in a vague, simplistic or even misleading manner. We re-analyzed this data and specifically looked at the reporting structure and whether or not insufficient information was given in these studies, i.e., which studies were unclear with respect to one or more of these characteristics. Fig. 1 shows that the underlying data sources are documented in all studies; also descriptions of the model and of indicators used are given. For data and where model descriptions are given respectively, 10% and 2% of the papers gave insufficient information (Fig. 1a–c). However, this does not necessarily mean that these studies were not reproducible. Between 45% and 80% of the studies also did not give sufficient information, concerning the results' uncertainty and validation (Fig. 1e and f). More than 75% excluded scenario analysis and more than 60% of the studies did not involve stakeholders. The important point to note here is that this inconsistency hinders a synthesis or comparison of these studies given the differences in basic elements of the analysis. This variety of methodological approaches is, on the one hand, a creative scientific process and typical of the development of new concepts, however on the other hand, it risks confusing the message to the larger community of users of the concept. Finally, it is interesting that well-known papers on best modeling practices for environmental modeling are totally neglected in ecosystem service studies (Jakeman et al., 2006).

The inconsistency hinders not only the scientific synthesis, but makes it also impossible to use systematically the concept to underpin and implement directives and economic instruments for conservation and ecosystem management, beyond a case-by-case policy development.

3. A reporting blueprint for ecosystem service assessments

To foster development of a more structured approach in which synthesis, comparison and guidelines is performing analyses are readily transferable and reliable we propose a reporting blueprint framework. A blueprint is recommended for documenting ESA to ensure a full list of important aspects are covered, and not overlooked within a specific application. Such a blueprint will:

1. reveal methodological aspects important for the interpretation of results;
2. support robustness and reliability of assessments;

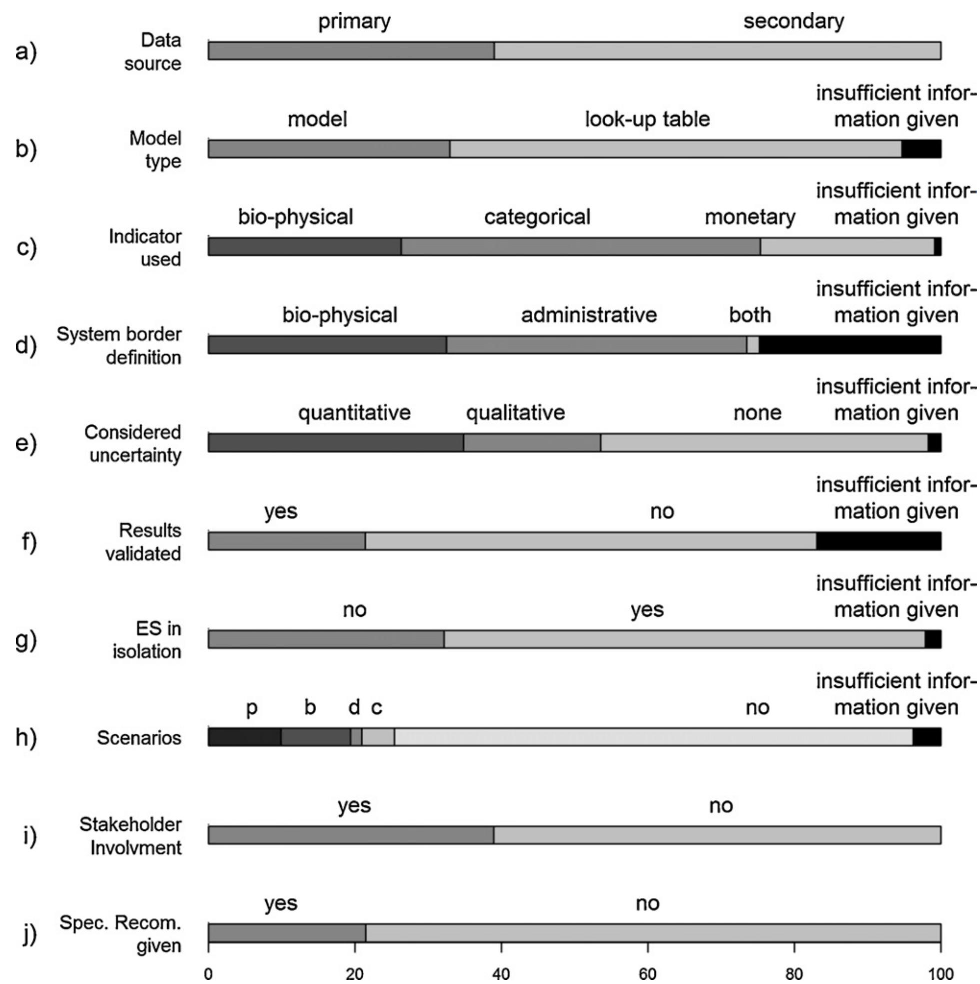

Fig. 1. Statistical overview of studies analyzed in Seppelt et al. (2011). It shows the percentage of studies (total 153) that belong to the specified indicator (from (a) data source to (j) recommendation given in study). Here we focus on the factor level 'insufficient information given' which refers to cases in which no information was provided in the publication for further analysis or application of results. The factor levels for scenarios are: p, political; b, behavioural; d, demographic; c, climate change.

3. aid in structuring ESA and monitoring programs;
4. provide a base for comparing and synthesizing results of ESA;
5. assist in achieving improved communication and collaboration in transdisciplinary teams; and
6. provide a base for further implementation of ESA.

Acknowledging that a blueprint needs to cover scientific, technical, implementation and practical aspects, we see a meta-data-catalogue on ESA as an incredibly challenging objective. Compared to the conceptual framework as outlined by Ash et al. (2010, Fig 1.1), we focus on the step of frameworks and analysis. This focus allows discussion on the structure of the conceptual framework and the state and trend analysis scenarios, and enables further extension by including the monitoring aspect, which is also not discussed by Ash et al. (2010).

Table 1 summarizes the major elements of the proposed blueprint for ESA. It reflects the fact that any implementation of the ecosystem service concept requires a careful clarification of the Purpose, Scope, Analysis, Recommendations, and Monitoring (PSARM) to be undertaken which necessitates the involvement of scientists and stakeholders. As a consequence, the natural science, modeling and calculation of indicators contribute only a small portion of the overall effort in terms of performing and documenting an ESA. All sections of the blueprint defined contain a sequence and build on each other, i.e., the results of one step of the blueprint determine the next, but at the same time guarantee that no aspect or option of freedom of choice is ignored. Below we provide an expanded explanation of the PSARM Blueprint.

3.1. Purpose and design

The starting point for any environmental and ecosystem service assessment is to define the purpose, including the specific objectives and the study design best suited to those ends. Although probably stating the obvious in this section of the blueprint, the reviews quoted above, indicate that information on these issues is frequently too short, with the design driven by the availability of data, indicators or modeling tools. This purpose and design should be accompanied by some administrative information about the people involved, the funding agency to address potential conflicting interests, the intended audience for the ESA results, and desired outcomes/expectations. According to the expected influence of the further process of the assessment, selection of stakeholder and practitioners should be documented.

Based on this clear statement of the purpose and design, a null hypothesis can be drafted: What is your expectation that including/excluding certain indicators and feedbacks from your study does to modify the results and how? What are the expected relations between ecosystem services and benefits or human well-being as well as the related policy measures? If desired, then storylines for a possible scenario analysis need to be elaborated at this point.

With this section completed the main characteristics of an ESA are summarized and this information can be used for retrieving best practice examples for certain problem fields, environmental pressures, stakeholder settings, etc.

3.2. Scope of problemscape and illustration of the concept

In this section, the PSARM Blueprint calls for a sufficiently detailed system description that includes information on spatial and temporal scale, environmental attributes (e.g. climate, topography, etc) and socio-economical (landowners, land use, land use transitions, etc) and socio-cultural aspects (value systems, aesthetics, role of landscape and land use in identity formation), the relevant ecosystem services can be defined, measured in physical units or, for cultural services, described by ordinal classes. This allows identifying and describing the relevant policy measures (conservation activities, allowable use, who pays for use for exclusion of use?).

Additionally, the system analyses should also take into account, which flows of ecosystem services are found within the region of interest as well as across the system boundary. Only by taking this into account at a very early stage, sinks and sources of ecosystem service can be identified and flows of ecosystem goods and services are characterized. Specifically the access to goods and services (excludability of use) is key to answer questions like "what happens between the site of the provision and the service user?" and "who are the beneficiaries and who are the losers?". Related to this the specification of the use of services with respect to rivel or non-rivel goods and service needs to be given, too. Both aspects lay at the heard of the management of common goods, such as ecosystems services and are key for next steps of assessment, modeling and conflict analysis.

A statement should then follow describing the main threats from and to the environment, the economy and the social aspects as well as a definition of the environmental, economic and social targets. Since the stakeholders' selection is very likely to influence the outcomes of the study, they should be identified here as well. If the study uses scenarios, the related storylines should also be reported.

To provide clarification about the purpose and to support transdisciplinary communication, definitions of terms and relations should be given – for instance through a glossary or a conceptual diagram. The conceptual diagram could be developed for instance in a moderated modeling process. This should be accompanied, following the concept from CICES (EES, 2010), by a specific list of ecosystem functions, ecosystem services and benefits.

With the finalization of this step, a complete overview of all available (or missing) data and information in the study region needs to be provided. Together the null hypothesis (Section 3.1) and available data (Section 3.2) form the foundation for the selection of tools and methods for the analysis and assessment (Section 3.3). At the end of this step, or blueprint section the basic conditions and all determining factors are clearly outlined and specified. All degrees of freedom for possible management options are summarized and all institutional constraints are known and documented.

3.3. Analysis and assessment

This section of PSARM reports on the methodological analysis of ESA. The first step in the analysis, based on the project purpose and scope, is defining the selected indicators for ecosystem services, including biophysical units of the cardinal indicators and the ordinal classes for cultural services. The indicators should specify whether the focus is on the supply or the demand side of ecosystem services. The inventory of ecosystem services should be documented. If appropriate, then quantitative aspects of scenarios should be reported which might include certain rates of change of driving variables or a specification of the development of land use scenarios.

The calculation of indicators on ecosystem functions, ecosystem services and benefits should be given in clear reproducible (biophysical or ordinal scale) units together with a description of the methodology used. Explicit statements on the uncertainty in form of error bars, standard errors or confidence/credibility intervals should be given and non-quantifiable sources of uncertainty should be made explicit (such as unclear relations of ecosystem function and service, existence of time lags, thresholds, or tipping points). If any kind of simulation model is used for derivation of results, it is important to include the criteria used for the selection of models and methods, as well as the criteria that have been used to assess the reliability of the models and the analysis and test of results (including uncertainty). Note, not all items are necessarily applicable to all assessments depending on the specific ESA methodology chosen (see worked example in Section 4 and in Supplementary material).

The same information is to be provided for the valuation and the services calculated based on the indicators. The test of the results' robustness should be done with respect to (a) the scenarios; (b) internal parameter assumptions; and also (c) against real world data. In addition, data should also be reported that is endogenous/exogenous to the analysis and should include off-site effects.

This section is crucial to the natural science component as it relates ecosystem function to the demand of ecosystem services. The use of the storylines from Section 3.1 and the quantification (of indicators) reduces the complexity of the analysis. The discussion of scope from Section 3.2 provides the information for the selection of model and indicators. Together they both provide a first analysis of ecosystem service assessments; however this needs to be accompanied by a data and uncertainty analysis. With the availability of information of this part of the blueprint, ecosystem service assessments will be comparable and helpful for further development of policy measures.

3.4. Recommendations and results

In contrast to the meta-information of model reporting in the previous section, this section provides guidelines for communicating the unique aspects of each ESA to the appropriate players who can act on the information. Results should be interpreted with regard to the underlying assumptions but also with respect to the stakeholders involved in the process; ideally, referring to the stated null-hypothesis acknowledged in Section 3.1. Interpretations and guidelines with respect to the identified uncertainty should also be added. With the readily developed classification of ecosystem services and the indicators at hand to measure them, policy measures can be defined. Following the DPSIR classification, they could be aimed at mitigating impacts, relieving pressures or reorienting drivers, on different spatial and temporal scales (Binimelis et al., 2009; Spangenberg, 2007). This analysis takes into account the characterization of ecosystem goods and services with respect to its accessibility. Do demands match (in space and time) with provisioning? Are any unintended or unknown sinks identified? Based on this recommendations can take into account the issues of trade-offs and unintended on- and off-site effects.

According to Rodríguez et al. (2006), trade-offs occur due to feedback in ecological processes resulting in temporal and spatial patterns when gains and losses do not occur in the same region. It is even possible that the same function is considered a valuable service in the area analyzed, but as a disservice outside (and vice versa) depending on the respective anthropogenic use pattern (Sagoff, 2011). Furthermore, effects in regions that are not considered in the ESA or that might have delayed impacts can be found. The

Table 2
PSARM Blueprint template for reporting ecosystem service studies.

(1) Purpose and design	• Rationale, scope of study, project goals • Main threats • Targets: ecosystem service, biodiversity, economic and social targets and objectives • Team of scientist • Report on stakeholder, practitioners identification, selection
(2) Scope of problemscape and concept	• System description: clarification of terms and relations, describe socio-environmental system investigated in space and time, sketch conceptual model • Give clear definition of ecosystem services (physical units, qualitative description for cultural services). • Give details on landscape: scale, extend, landowners, land use, transitions • Characterize ecosystem services with respect to its accessibility rivel/non-rivel services as well as accessibility and right to use (excludable/non-excludable service) • Report on policy measures: conservation activities, allowable use, who pays? • Clarify expectations, e.g. null hypothesis • Storylines of possible futures
(3) Analysis, assessment	• Selection of cardinal indicators with their biophysical units, ordinal for cultural services • Inventory of ecosystem services, indicator calculation • Criteria for selection of models, biophysical realism, test criteria for reliability of model and analysis results, documentation of methods applied (models, assessments, indicators) • Quantification scenarios • Provide analysis including valuation • Test of robustness with respect to scenarios as well as internal parameters assumptions, test with real world data
(4) Recommendation and results	• Analysis of trade-offs, ecosystem service bundles • Analysis of flows of ecosystem services (sinks, depletion, use), e.g. identification of off-site effects • Suitability of policy measures • Summary, recommendations • Interpretation of results with respect to stakeholder, practitioner assessments
(5) Monitoring	• Identify core indicators for monitoring changes in respect to ecosystem services, biodiversity, economic and social targets and objectives • Identify possible options for modifications of measures or instruments • Define frequency of monitoring

recommendations should then indicate when there is a flow in ecosystem services over the boundary of the investigated region. Thus, based on the analysis of sources and sinks of ecosystem goods and services and their spatio-temporal pattern, the flows and accessibility, trade-offs and unintended consequences can to be identified, summarized, and reported for the considered region with its landscapes and ecosystems, as well as with the policy measures.

This section reports results of the biophysical analysis of ecosystem functions and services based on data, indicators, and models. The two major aspects are trade-offs and off-site effects. The most innovative aspect is the trade-off analysis of assessments, e.g. the analysis of several objective indicators (ecosystem services) with respect to contradicting objectives. Based on these pareto-frontiers recommendations for practitioners can be derived.

Table 3
Worked examples of blueprints for ecosystem services studies. See Supplementary material (SA) for full elaboration.

	Title/topic	Main purpose	References	Blueprint
1	Integrated costal zone management	Offshore wind power puts pressure on marine species, tourism, and fishery. Integrated analysis should provide options which are socially accepted	Burkhard et al. (2011), Gee and Burkhard (2010), Lange et al. (2010), Kannen and Burkhard (2009)	This table, main text
2	Sustainable land-use practices in mountain regions	Development of adapted land use practices that warrant the life-supporting services required for sustainable development, are economically and ecologically efficient, and socially and politically feasible	Dawes et al. (2011), Eilmann et al. (2011), Dobbertin et al. (2010), Hirschi (2010), Balsiger and Hirschi (2010)	Table S1
3	Testing methodology for ex-ante evaluation of (land use) policy impacts on ecosystem services	Evaluation of the ecosystem service impacts of existing policies related to land use. Interactions between measures and trade-offs between ecosystem services may not fulfil the expectations of the policy package in terms of ecosystem services.	Willemen et al. (2008, 2010)	Table S2
4	Market based Agri-Environment schemes for Biodiversity protection	Promotion of ecosystem service provision in agricultural landscapes through the implementation of an outcome-oriented, market-based agri-environmental scheme to maintain and enhance biodiversity	Bertke et al. (2008a, 2008b) Höft et al. (2008), Klimek et al. (2010)	Table S3
5	Ecosystem services in Urban Regions	Assessment of ecosystem services in urban regions for understanding of the function of brown fields and urbanization on ecosystem services provided by urban region	Bastian et al., 2012	Table S4
6	Integration of landscape structural aspects into regional development planning	Jointly the development of the approach from scientist, foresters and farmers for integrated rural development of region Dresdner Heidebogen, Germany	Barkmann (2001), Frank et al. (2012), Renetzeder et al. (2010)	Table S5

Table 4
Integrated Coastal Zone Management (ICZM) and offshore wind power OWP (Burkhard et al., 2011; Gee and Burkhard, 2010; Lange et al., 2010; Kannen and Burkhard, 2009).

Purpose and design	**Scope of the study:** Interdisciplinary research on Integrated Coastal Zone Management for the specific example of future offshore wind power (OWP) installations. **Project goals:** Develop strategies for a multifunctional sustainable use of German coastal zones, including the installation of up to 90 GW OWP capacity maximum. **Main threats:** Environmental threats include OWP impacts on migrating birds, marine mammals and shipping safety. Economic impacts are related to the tourism industry, fishery and further competing uses. Analysis of societal acceptance of OWP, participation and governance. **Targets:** Impacts of potential future OWP installations on the provision of relevant marine ecosystem services and effects on coastal communities. **Stakeholders:** Individuals, groups or institutions influencing or being influenced by future developments at the west coast of Schleswig-Holstein; i.e., OWP operators, local residents, nature protection administration and NGOs, tourism operators, fishing companies or the Federal Maritime and Hydrographic Agency. **Team of scientists:** GKSS Research Centre Geesthacht, Kiel University and Hamburg University as main contract partners (see Lange et al., 2010).
Problemscape and concept	**System description:** The German North Sea is characterized by strong land–sea interactions; ecosystems and relevant ecosystem services potentially affected by OWP are mainly located in the marine area, whereas the benefits are demanded in the adjacent coastal regions. **Ecosystem services** as relevant for OWP: • Regulating ecosystem services (climate regulation, sea bed control, water purification and waste treatment, storm protection), • Provisioning ecosystem services (food fishery, food co-use mariculture, wind energy, biochemicals), • Cultural ecosystem services (aesthetics, beauty of landscape, sense of place, cultural heritage, habitat and species value, regional image, inspiration, informal education, knowledge systems, recreation). Ecosystem service show all characteristics of common goods: non-rivelness (climate regulation, water purification, storm protection, aesthetics) as well as non-excludability (mariculture, food fishery, etc.). Potential changes in their future provision were assessed and links to human well-being (social, economic & personal well-being) established. **Landscape** (Seascape): A nested multiscale approach was applied, spatially referring to a local, regional, national and international scale. In terms of OWP "local" means one single wind turbine, "regional" refers to one wind park, "national" to the German Exclusive Economic Zone and "international" to the southern North Sea. Temporally, the time steps 2005, 2010, 2030 and 2055 were analyzed for the five scenarios mentioned above. **Policy measures**: In order to fulfil its ambitious CO_2 reduction targets of 20% by 2020 (as set by the EU), the former German government strongly promoted the use of renewable energies, i.e., OWP. By 2010, renewable energies were planned to provide 12.5% of the total German electricity generation. These plans are conflicting with an already dense pattern of existing sea and coastal uses and nature protection measures. **Expectations/Challenges**: Besides first experience from OWP in other European countries, little is known on environmental impacts, technical feasibility, economic efficiency and social acceptance of OWP. Hence, new knowledge and data with regard to OWP in Germany are expected to be achieved, especially as marine/coastal areas are rather underrepresented in ecosystem service studies so far. **Storylines of potential futures:** Five different future sea/coastal use preferences were defined (energy generation, nature protection, industry, tourism, shipping) until the year 2055. For these five use preferences, varying intensities of OWP deployment were defined in capacity (MW) and space (wind park areas).
Analysis, assessment, test	**Indicators:** Derivation based on the DPSIR model: *Drivers:* (a) direct drivers: societal demand for materials and energy, health, social relations, security, freedom of choice and action, education; (b) indirect drivers: demography, economy/markets/trade, economic globalization, institutional and cultural globalization, social policy, norms and values, science and technology, *Pressures:* sea and coastal uses: military, protected areas, fishery, shipping, coastal protection, raw material extraction, tourism, agriculture, cable and pipelines, waste disposal, mariculture, infrastructure, OWP, *State:* (a) ecosystems: energy cycling (NPP in g C/m^2/a), nutrient cycling (winter turnover of nutrients), storage capacity (t C stored in biomass), minimization of nutrient loss (transport loss of nutrients), abiotic heterogeneity (current velocity in m/s, water turbidity, sediment parameters), biotic diversity (diversity index sea birds), ecosystem organization (ascendancy); (b) social state: infrastructure, social cohesion, regional identity, individual quality of life; (c) economic state: economic structure, labor, markets, regional wealth based on capital stocks and fixed assets, personal wealth, regional dependency on social transfers, *Impacts*: on (a) the provision of ecosystem services (as mentioned above); (b) human well-being (social and economic welfare indicators), *Response:* coastal zone management measures, environmental impact assessments, participation **Ecosystem service indicator calculation:** Linked ecological and socio-economic assessments of OWP future scenarios based on (a) ecological modeling, (b) economic input-output modeling (effects on employment), (c) expert assessments, and d) interviews ("values" and cultural services) **Models**: For the assessment of ecosystem effects, a coupled model approach linking:ERSEM (ecosystem model; Lenhart, 2001), Ecopath (food web simulations; Christensen and Pauly, 1992), MIKE21 (water current & sediment dynamics; Jones et al., 2007), GIS data (sea birds' and marine mammals' abundance; Garthe and Hüppop, 2004). An economic input–output model was used to calculate effects on employment in wind power related industries (Lange et al., 2010). **Scenario quantification:** Ecological modeling: existing environmental OWP data (monitoring in European countries with existing OWP), EIA for OWP, literature data Cultural ecosystem services: interviews about local people's values and preferences Provisioning services and human well-being: expert assessments. **Valuation and test:** Modeled OWP impacts were normalized to a relative scale ranging from −2 (very negative impact on respective ecosystem service's provision), 0 (no impact) to +2 (very positive impact) and −1 and +1 (as respective intermediate values).
Recommendation and results	**Trade-off analysis and off-site effects:** Positive impacts of OWP were modeled for the regulating service global climate regulation, the provisioning services energy (electricity from OWP) and food (from new fish nursery areas and mariculture) and for employment. For the other selected ecosystem services, the developments are very much dependent on future dynamics (e.g. whether "artificial reef effects" occur at the offshore installations) and individual opinions/values (e.g. cultural ecosystem services aesthetics, beauty of landscape or recreation). **Recommendations**: The OWP-related chances identified have to be perceived and seized accordingly, e.g. by policy support of regional employment within production and maintenance of wind turbines. Environmental risks can be minimized by proper environmental impact assessments, careful positioning of the wind parks and public participation (information/education but also regional shareholder allocation).
Monitoring	Not established at the end of the project.

Table 5
Frequently asked questions (FAQ) within applications of the blueprint.

Are scenarios, simulation experiments, models and sensitivity analysis part of the blueprint?
Yes, compared to other documentation schemes such as meta-data catalogues this is of specific importance. Scenario definition is a crucial part as it determines indicators selection and model sections.
Should the elements of the blueprint always be presented in the given sequence?
Yes. Although it is not meant to structure an assessment study, we expect different iteration loops in a regular assessment, but the iteration steps should follow this documentation scheme.
What if a journal or report does not support this format?
The blueprint should be used to structure the regular work in an ecosystem service assessment study. It can be also used in a recursive manner: sub-studies and analysis can be structured accordingly. As a final outcome, parts can be used for reporting and project documentation as well as supplementary material in a scientific journal paper.

3.5. Monitoring and continuation strategies

The ESA is not complete unless there is ongoing activity to support the study and recommendations. Monitoring supports a continuous control of possible implemented measures. The final part of the ecosystem service blueprint provides stakeholders and scientists with information on how to manage the system after the assessment. This involves identifying core indicators for monitoring changes in respect to ecosystem services, biodiversity, economic, and social targets and identifying possible options for modifications of these measures or instruments. More broadly, an ESA provides information on the crucial indicators for the overall environmental condition of the region and can be used to help assess and manage human resource use. The result of this step is the recommendation of specific indicators and procedures for monitoring the future development.

4. Worked example – sample applications

For testing purposes of the PSARM Blueprint (Table 2), several former studies on ESA, as well as selected case studies from this special issue, were analyzed using the blueprint to develop concise documentations for each case study (Table 3). Besides the first case study on integrated costal zone management (Table 4), all examples can be found in Supplementary material of this paper. We discuss the practical implications of our blueprint taking into account the experiences from the worked examples of Supplementary material (Table 3), but use the example in Table 4 for specifically pointing out important results.

The case study reported in Table 4 refers to an analysis of offshore wind power in the context of Integrated Coastal Zone Management, see Burkhard et al. (2010), Gee and Burkhard (2010), Lange et al. (2010), Kannen and Burkhard (2009). It specifically focuses on the analysis of a set of ecosystem services and their interactions, feedbacks and trade-offs. Positive impacts of off-shore wind power were identified for the regulating service global climate regulation, the provisioning services energy and food (from new fish nursery areas and mariculture) and for employment. Uncertainties for all other selected ecosystem services are identified, as these are dependent on future dynamics. The blueprint gives an overview of the underlying methodologies, the identified weaknesses and derived recommendation related to those results.

Two important aspects of the application of the blueprint for documenting ecosystem assessment studies can be derived form these examples. First, while all cases provide most of the requested information, none reported on all the aspects recommended in the blueprint in full detail. This illustrates one of the strengths of such a blueprint: It provides a full list of important items for the reported on, so that the information given is usable for further analysis.

Second, the blueprint provides a framework for a concise, yet complete, summary of the case studies. This information is useful for consistency of reporting and meta-analysis. If a blueprint had been available studies such as TEEB, Goldman et al. (2008) and Seppelt et al. (2011) would have been able to analyze regional studies more in-depth, would have been able to provide a more in depth analysis of regional studies.

Forth, the blueprint can be used to provide multiple levels of detail. The blueprint can be used either for providing meta-information or it can be used for structuring an in-depth – probably technical – report with full information on the entire process of a study. All worked examples made use of references to further publications on issues that were not resolved fully within the 1–2 page abstract, see for instance Table 4 for model applications or example 1, Table S2 for valuation methods. So the blueprint can be used in a hierarchical way. Either providing a concise and full fetched overview as well as a structure for complete in in-depth reports. The sample applications for these case studies showed that a proper documentation is feasible by using the suggested blueprint framework. Both, comparability as well as reproducibility of the individual studies improved substantially.

5. Conclusions and discussion

Structuring complex processes such as elaborated here for ecosystem service assessments is a typical task in environmental models. A comparable concept was published by Grimm et al. (2006), developing a protocol for application to individual-based models in ecology. It has proven to be effective and successful as evidenced by its use in structuring different models, developing projects (for instance Ph.D. projects) and its frequent application within model description in papers.

We are motivated by that success and anticipate that the proposed PSARM Blueprint in this contribution will provide continued practical assistance for performing and comparing ESA while strengthening the political relevance of the ecosystem services concept. The blueprint will be helpful for scientists implementing an ESA and will also be a guideline for stakeholders as it captures their understanding of the environmental problem at hand. Due to the fact that we capture not only the system analysis component, which is well known to environmental scientists, but also recommendations and monitoring issues extending the PSARM Blueprint beyond concepts which focus only on the natural science component.

Against this background, the blueprint is by no means a constraint in terms of performing an ESA. It keeps enough flexibility but structures the output of the assessment study. There might be concerns with respect to its usability within scientific publications, see Table 5. But in general it supports revealing methodological aspects, which is important for judging results. In this way, it supports reliability of findings and results. The blueprint helps to compare results of different studies and supports comparing mechanisms or instruments derived from ESA. Solutions for improving environmental management need to be adapted and perhaps even developed for each case study separately. Given this structured blueprint, one can address regional environmental problems more systematically by comparing these cases.

We have demonstrated that the incorporation of different kind of information (starting hypothesis, conceptual issues, biophysical data, aspects on stakeholder involvement) is urgently needed as it helps working in inter/transdisciplinary teams. Furthermore the working with the blueprint could also be seen as a iterative process, sharpening the information given in each iteration loop.

Finally, it will also be valuable for structuring monitoring strategies. By making use of available concepts and existing review and meta-analysis studies, the blueprint ensures consistency and avoids new definitions as it refers to existing concepts. The more clearly these studies are documented, the better the reproducibility of this type of analysis, providing more credibility for the ecosystem service concept and all upcoming political instruments grounded on this concept will be achieved.

Supplementary material

Worked examples: Table 3 gives an overview of the worked examples on ecosystem service studies documentations based on the blueprint, which can be found in Tables S1–S5 in the supplementary material.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecolind.2011.09.003.

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