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Editorial

Solutions for sustaining natural capital and ecosystem services

The topic of ecosystem services has attracted significant attention in the last decades. This has involved the development of new analytical methods and models, substantial data collection, and major initiatives such as the MA (Millennium Ecosystem Assessment[1]), TEEB (The Economics of Ecosystems and Biodiversity[2]) and IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services[3]). It is even more urgent that we meet the challenge identified by Daily et al. (2009) that it is 'time to deliver and to make ecosystem services operational'. On the basis of the significant interest that the notions of ecosystem services has attracted in the management and policy communities, it is essential that we use the research results to find solutions for sustaining natural capital and ecosystem services.

As part of the evolving ecosystem services discussion, a series of conferences has been organized by the Ecosystem Services Partnership (ESP[4]). The series began in 2008 with a conference entitled "Ecosystem Services – Solution for problems or a problem that needs solution?". It resulted in a Special Issue of the journal *Ecological Complexity* (Burkhard et al., 2010). The series of conferences continued in 2009, with "Modeling Ecosystem Services" (focusing on modeling and quantification approaches), and 2010, with "Solutions for Sustaining Natural Capital and Ecosystem Services" (the focus here was on solutions for the problems identified in the prior conferences). The most recent conference was held in 2011. It dealt with "Ecosystem Services: integrating Science and Practice". Looking forward to 2012, the meeting will be dedicated to "Ecosystem Services Come of Age – Linking Science, Policy, and Participation for Sustainable Human Well-Being". The titles of these five workshops already suggest the continuous dynamic and steady maturation of the ecosystem service idea – from problems, via models to solutions, which can be applied by the science and practice communities for sustaining human well-being. Thus, an emerging need for scientific development, as well as fostering of applications and environmental management based on of the ecosystem service concept (Seppelt et al., 2011), has been identified. Given this background, a major achievement is the "Salzau Message" (see Box 1), signed by the participants, which summarizes the required next steps in research and application for sustaining natural capital.

[1] http://www.maweb.org.
[2] http://www.teebweb.org.
[3] http://ipbes.net.
[4] http://www.es-partnership.org.

It is in this developing context that the contributions to this special issue of Ecological Indicators, that originated from the 2010 ESP conference held in Salzau in northern Germany,[5] must be viewed. They are especially focused on research aimed at finding solutions for environmental management problems based on the ecosystem service concept. When looking at the individual papers of this Special Issue, the solution-oriented focus is demonstrated by the fact that:

(i) Most of the articles are related to broad bundles of ecosystem functions and services (e.g. Koschke et al., 2012; Scolozzi et al., 2012; Burkhard et al., 2012) instead of focusing on selected services like many former studies;
(ii) Articles focusing on selected ecosystem services apply methods, data and models, which are characterized by a higher level of complexity and are embedded in broader ecosystem service contexts (e.g. Haines-Young et al., 2012; Frank et al., 2012; van Oudenhoven et al., 2012; Nedkov and Burkhard, 2012);
(iii) Several articles apply and/or present comprehensive assessment approaches or ecosystem service frameworks (e.g. Bastian et al., 2012; Syrbe and Walz, 2012; Seppelt et al., 2012; Busch et al., 2012); and
(iv) Demonstrate a clear link to practical applications and decision-making (e.g., Schneiders et al., 2012; Jørgensen and Nielsen, 2012).

This demonstrates that the ecosystem service research has moved forward substantially and made progress in addressing research questions which moved from introductions and questioning the concepts to far more specific detailed questions about methods and applications. The discussion around these themes can be seen as taking the ecosystem service research agenda forward in relation to two broad topics:

First, under the topic "Characterizing and Measuring Natural Capital and Ecosystem Services", two different issues were discussed:

1. **Integrated quantification, modeling, and valuing of ecosystem services**: How can we measure and evaluate ecosystem services? How can we link ecosystem functions, services and benefits? How can ecosystem services be explicitly linked to human well-being?

[5] http://www.uni-kiel.de/ecology/projects/salzau.

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Box 1
"Salzau Message'' on Sustaining Ecosystem Services and Natural Capital

The human population of earth is likely to increase to 9 billion people by the end of the century, the global climate is being transformed, biodiversity loss continues, and conventional, fossil-based economies are no longer a viable option. Business as usual is a utopian fantasy. If we are to improve the sustainable well-being of humanity, we need to sustain and restore ecosystem services and natural capital. Stakes are high. The potential for irreversible, negative, outcomes is alarming, and a precautionary approach to decision-making should therefore be adopted.

We, the undersigned, believe that solutions to providing a sustainable and desirable future require broad recognition of the basic facts about ecosystem services and natural capital, and advances in two key areas: (1) integrated measurement, modeling, valuation and decision science; (2) adaptive management and new institutions, including the new Ecosystem Services Partnership discussed below.

Basic Facts about Ecosystem Services and Natural Capital

In recent decades, a shared understanding has emerged about ecosystem services and natural capital, including:

- Ecosystem services (ES) are the contributions of ecosystem structure and function – in combination with other inputs – to human well-being.
- ES, and the natural capital assets that produce them, represent a significant contribution to sustainable human well-being, a contribution that is increasingly being recognized.
- Ecosystems, ecosystem functioning, and ES are being threatened and degraded by human activities, and the situation will be exacerbated by climate change and biodiversity loss. At the same time, knowledge about how to steward and restore ecosystems is rapidly growing.
- An ES approach helps to identify and quantify the ecological and socio-economic trade-offs and synergies on which decision-making should be based.
- Many ecosystem services cannot (or should not) be privately owned. Therefore, they are for the most part ignored by conventional markets.
- Many ES are such that providing benefits to one person does not reduce the amount of benefits available for others. They are "non-rival" and "non-excludable". They are therefore best treated as "public goods".
- While tremendous progress has been made in improving our understanding of how ecosystems function and how humans benefit from them, there will remain enormous uncertainties about how ES are provided, the magnitude of their benefits, and how human activities affect their provision.
- Adaptive management is a useful approach that allows one to learn from the system dynamics and manage under this uncertainty.

1. Integrated Measurement, Modeling, Valuation and Decision Science in Support of Ecosystem Services:

The scientific community needs to continue to develop better methods to measure, monitor, map, model, and value ecosystem services at multiple scales. Moreover, this information must be provided to decision makers in an appropriate, transparent, and viable way, to clearly identify differences in outcomes among choices. At the same time, we cannot wait for high levels of certainty and precision to act. We must synergistically continue the process of improvement of measurements with evolving institutions and approaches that can effectively utilize these measurements.

a. Trade-offs

Ecological conflicts arise from two sources: (1) scarcity and restrictions in the amount of ES that can be provided and (2) the distribution of the costs and benefits of the provisioning of the ES. ES science makes trade-offs explicit and, thus, facilitates management and planning discourse. It enables stakeholders to make sound value judgments. ES science thus generates relevant social-ecological knowledge for stakeholders and policy decision makers and sets of planning options that can help resolve social conflicts.

b. Accounting and Assessment

Accounting looks at the flow of processes or materials and is relatively objective, while assessment evaluates a system or process with a goal in mind and is more normative. Both are integrating frameworks that have distinctive roles. Both ecosystem service accounting and assessment need to be established and pursued in a broader socio-ecological context. We also need to balance expert and local knowledge across scales.

c. Modeling

We need modeling to synthesize and quantify our understanding of ES and to understand dynamic, spatially explicit trade-offs as part of the larger socio-ecological systems. Further participatory development of integrated, dynamic, spatially explicit models that include ES are needed. These models can incorporate and aid accounting and assessment exercises and link directly with the policy process at multiple time and space scales.

d. Bundling

Most ES are produced as joint products (or bundles) from intact ecosystems. The relative rates of production of each service vary from system-to-system, site-to-site, and time-to-time, but we must consider the full range of services and the characteristics of their bundling in order to prevent creating dysfunctional incentives and to maximize the benefits to society. For example, focusing only on the carbon sequestration service of ecosystems may in some instances reduce the overall value of the full range of ES.

e. Scaling

ES are relevant over a broad range of scales in space, time, and complexity. We need measurement, models, accounts, assessments and policy discussions that address these multiple scales, as well as interactions and hierarchies among them.

2. Adaptive Management and New Institutions for Ecosystem Services:

Given that significant levels of uncertainty always exist in ecosystem service measurement, monitoring, modeling, valuation, and management, we should continuously gather and integrate appropriate information regarding ES, with the goal of learning and adaptive improvement. To do this we should constantly evaluate the impacts of existing systems and design new systems with stakeholder participation as experiments from which we can more effectively quantify performance and learn.

a. Property Rights

Given the public goods nature of most ecosystem services, we need institutions that can effectively deal with this characteristic using a more sophisticated suite of property rights regimes. We need institutions that use a balanced combination of existing private property rights systems, and new property rights systems that can propertize ecosystems and their services without privatizing them. Systems of payment for ecosystem services (PES) and common asset trusts can be effective elements in these institutions.

b. Scale-matching

The spatial and temporal scale of the institutions to manage ecosystem services must be matched with the scales of the services themselves. Mutually reinforcing institutions at local, regional and global scales over short, medium and long time scales will be required. Institutions should be designed to ensure the flow of information between scales, to take ownership regimes, cultures, and actors into account, and to fully internalize costs and benefits.

c. Distribution Issues

Systems should be designed to ensure inclusion of the poor, since they are more dependent on common property assets like ecosystem services. Free-riding should be prevented and beneficiaries should pay for the services they receive from biodiverse and productive ecosystems.

d. Information Dissemination

One key limiting factor in sustaining natural capital is shared knowledge of how ecosystems function and how they support human well-being. This can be overcome with targeted educational campaigns, clear dissemination of success and failures directed at both the general public and elected officials and through true collaboration among public, private and government entities.

e. Participation

Relevant stakeholders (local, regional, national, and global) should be engaged in the formulation and implementation of management decisions. Full stakeholder awareness and participation contributes to credible, accepted rules that identify and assign the corresponding responsibilities appropriately, and that can be effectively enforced.

f. Science/Policy Interface

ES concepts can be an effective link between science and policy by making the trade-offs more transparent. An ES framework can therefore be a beneficial addition to policy-making institutions and frameworks and to integrating science and policy.

ECOSYSTEM SERVICE PARTNERSHIP

The new Ecosystem Services Partnership (ESP – http://www.es-partnership.org/) seeks to enhance this integration by uniting the ecosystem services science and policy community and coordinating collaborative efforts on a global, national and local level. It aims to enhance and encourage a diversity of approaches, where needed, while reducing unnecessary duplication of effort in the conceptualization and application of ecosystem services. By increasing efficiency, and promoting better practice, the ESP aims to increase the effectiveness of ES science, policy, and applications.

Signed by:

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2. **Accounting for ecosystem services at the landscape level**: How can the ecosystem service approach be applied in landscape analysis, landscape planning and landscape management?

Second, under the topic "Designing Socio-Ecological Institutions", the following aspects were studied in detail:

3. **Adaptive management of ecosystem services**: What supporting tools have to be developed to enhance the applicability of the ecosystem service approach in adaptive management? How can the approach be implemented in management strategies and institutions?
4. **Environmental, social and economic trade-offs**: How can ecosystem services be evaluated from social and economic points-of-view? Which instruments should be developed to foster these evaluation strategies?

These topics and related questions illustrate that, one the one hand, solutions are needed for a proper assessment and valuation of ecosystem services and, on the other hand, for the applicability and implementation of the ecosystem service approach.

1. Integrated quantification, modeling, and valuing of ecosystem services

For integrated assessments we have to be aware that each ecosystem service approach contains uncertainties and generalizations related to scale issues, methodological issues, vague classifications and definitions (Scolozzi et al., 2012). Several ideas were proposed for a better taxonomy and classification of ecosystem services, because there is still no consensus on a common strategy (Seppelt et al., 2012; Burkhard et al., 2012). Bastian et al. (2012) emphasize the need for a clear differentiation between landscape/ecosystem functions, ecosystem services and landscape potentials, for which van Oudenhoven et al. (2012) provide a classification and indicator scheme. The different approaches illustrate that the definition of a common classification framework remains a major challenge, because ecosystem service studies are too singular, question-dependent and context-related. However, maybe the definition of a common classification framework is neither feasible nor really necessary (Costanza, 2008).

The inherent complexity of the topic itself, spatio-temporal dynamics and varying value definitions need to be considered when deriving common concepts (Scolozzi et al., 2012). One clear solution is to develop a proper documentation of the studies and the ecosystem service concepts behind them, like in the "blueprint" approach presented by Seppelt et al. (2012). The "blueprint" was successfully applied to several case studies, two of them included in this Special Issue (Frank et al., 2012; Bastian et al., 2012). Such strategies help to make different ecosystem service studies comparable and provide an important means of communication.

Schneiders et al. (2012) provide a good example for the linkage between land use intensity, biodiversity, ecosystem service supply and human well-being. These interrelations are undoubtedly one of the most burning issues in current ecosystem service science, and we still need to further improve our knowledge of ecosystem functioning (Koschke et al., 2012). The analysis of ecosystem structures and processes is a basic prerequisite to the ecosystem services approach (Bastian et al., 2012; Frank et al., 2012). Therefore, integrated assessments on functional units are needed rather than on administrative boundaries (Seppelt et al., 2012). But what are "minimum functioning areas" required for selected ecosystem service provision (Scolozzi et al., 2012)? How much area is generally needed for the supply of a specific service and which areas are available (Koschke et al., 2012)? What is the minimum amount of biodiversity needed for a sustainable use of ecosystem services, avoiding imports (Schneiders et al., 2012) that would avoid ecosystem service footprints in distant regions (Burkhard et al., 2012)?

The articles in this Special Issue present comprehensive tools and applications, providing answers to these highly relevant questions as well as suggesting solutions. For example, ecological models and related holistic indicators have become very powerful (Jørgensen and Nielsen, 2012) and are useful for ecosystem service assessments and environmental management (Nedkov and Burkhard, 2012). Expert-driven or literature-based approaches support ecosystem service modeling, providing a reasonable solution in cases where appropriate data are lacking (Haines-Young et al., 2012; Koschke et al., 2012; Scolozzi et al., 2012; Frank et al., 2012; van Oudenhoven et al., 2012; Burkhard et al., 2012). Busch et al. (2012) compare qualitative and quantitative ecosystem service assessment approaches (quantitative referring to monetary valuations in their case).

Comprehensive sets of indicators are needed for integrated assessments, and they need to be selected systematically and to reflect ecosystem properties, ecosystem functions and ecosystem services, as well as to represent land management as a main driving force for land use change (van Oudenhoven et al., 2012; Syrbe and Walz, 2012; Burkhard et al., 2012). Moreover, the indicators should be clear and understandable, enabling communication between scientists and other stakeholders. Therefore, robust procedures and guidelines are needed for indicator selection, as suggested in van Oudenhoven et al. (2012). Koschke et al. (2012) and Haines-Young et al. (2012). They should make use of multi-criteria approaches to find weighting systems and bundles of ecosystem services that are suitable to reflect different stakeholders' preferences and regional peculiarities.

Syrbe and Walz (2012) emphasize the importance of the spatial characteristics of ecosystem services and that indicators must be developed accordingly. Landscape metrics are a suitable solution to assess landscape structures and to account for their impact on ecosystem service supply. Frank et al. (2012) present landscape metrics as a necessary improvement of only land cover-based approaches. A comprehensive list of ecosystem services that are suitable for landscape metrics analyses is presented in Syrbe and Walz (2012).

2. Accounting for ecosystem services at the landscape level

The application potentials in landscape analysis, planning and management is the second key theme of this Special Issue. In regional planning, whole landscapes with multiple needs and demands, for example for different forms of land use, have to be considered (Koschke et al., 2012; Burkhard et al., 2012). Hence, tools for assessments of whole landscapes' ecosystem service potentials are needed (Busch et al., 2012) to bridge gaps between sectoral management landscape approaches and regional development planning (Frank et al., 2012). Scenarios have been shown to be useful tools to assess future development (Haines-Young et al., 2012).

In this context, a clear differentiation between ecosystem service capacities and ecosystem service or landscape potentials is essential in finding solutions in land use planning and "land use governance" (Bastian et al., 2012). Quite often, stocks of ecosystem services are quantified instead of actual flows (Haines-Young et al., 2012). Ecosystem function, service or landscape potentials refer to potential supply, whereas capacities are related to currently used ecosystem services (Burkhard et al., 2012; van Oudenhoven et al., 2012). Information of ecosystem service flows and respective awareness of ecosystem services in general are needed by decision makers (Scolozzi et al., 2012; Nedkov and Burkhard, 2012). Ecosystem service flows are closely related to demands for ecosystem goods and services (Syrbe and Walz, 2012). Regional demands for ecosystem services are especially relevant in landscape planning (Koschke et al., 2012; Nedkov and Burkhard, 2012; Burkhard et al., 2012). Additionally, "service-connecting areas", transferring matter, energy and organisms also have to be considered (Syrbe and Walz, 2012).

Frank et al. (2012) point out that easily applicable and integrated ecosystem service approaches are needed for landscape planning. These easily applied approaches, based on a relative scoring system to assess ecosystem service supply and demand, linked to various land cover units were suggested and applied in Burkhard et al. (2012) and in Nedkov and Burkhard (2012). Schneiders et al. (2012), Koschke et al. (2012) and Haines-Young et al. (2012) applied similar methods in spatially explicit quantification and comparison of ecosystem functions and service supply capacities in distinct landscape units. Schneiders et al. (2012), Koschke et al. (2012), Nedkov and Burkhard (2012), and Burkhard et al. (2012) highlight the importance of considering all land cover classes present in the study area in respective land cover-based assessments. The communication of land cover change effects on ecosystem services is very important for regional planning, which can be carried out with illustrative approaches such as "Pimp Your Landscape/GISCAME" (Koschke et al., 2012; Frank et al., 2012). Expert knowledge is useful for assessments of landscape capacities and potentials to supply ecosystem services, to evaluate impacts of land use changes (Haines-Young et al., 2012; Burkhard et al., 2012) and to adapt the tools to local conditions ("expert-based spatial adjustment"; Scolozzi et al., 2012). Scaling rules are suggested when transferring local data to larger scales and vice versa (Busch et al., 2012).

3. Adaptive management of ecosystem services

Tools, strategies and institutions are urgently needed, because the demand of ecosystem service-based instruments has currently been higher than scientists were able to deliver (Seppelt et al., 2012). Ecosystem services are very significant for adaptive management (Syrbe and Walz, 2012), but they have often been applied not appropriately or inconsistently. One reason could be that ecosystem service studies are often too complex for direct use in practical assessments (Koschke et al., 2012). Scolozzi et al. (2012) note that it is the decision making process which has to be addressed that determines the level of precision of the ecosystem service assessment and respective data to be used. Syrbe and Walz (2012) point out that spatial considerations are important for the maintenance of ecosystem services, not only for the assessments. The "blueprint" suggested by Seppelt et al. (2012) supports decision making by providing systematic documentations of methods, data, results and recommendations of ecosystem service studies. Therefore it could be used to guide how ecosystem service assessments are structured for practitioners.

Land use change, and associated gains or losses of ecosystem services, were identified and analyzed by Scolozzi et al. (2012), van Oudenhoven et al. (2012) and Haines-Young et al. (2012). Policy and environmental planning decide how land is managed and the resulting land management has important impacts on the provision of ecosystem services, at least on the regional scale (van Oudenhoven et al., 2012). Appropriate management has to bridge the gap between the present state and future targets for ecosystem services, ecosystem functions and biodiversity (Schneiders et al., 2012). The consensus between, for example, the lowest acceptable level of biodiversity and ecosystem services must be reached by society and policy, referring to "safe minimum standards of conservation" which should be linked to "safe minimum use" for land use intensities (Schneiders et al., 2012). Lookup tables or "rapid assessments" as suggested by Haines-Young et al. (2012) and Burkhard et al. (2012) are suitable solutions that show states and trends of ecosystem services, and help decision makers to prioritize areas for further analyzes and measures for the management of natural capital ("screening tools"; Scolozzi et al., 2012).

Integrated ecological-environmental management that follows the functional principles of ecosystems is necessary to identify measures and to find solutions for the current problems related to ecosystem management (Jørgensen and Nielsen, 2012). Most tools for environmental management have been developed as reactions to environmental problems. Today, a better understanding of complex ecosystem functionalities and even predictions of ecosystem behavior are possible, for example based on ecological modeling, ecological indicators and ecosystem services (Jørgensen and Nielsen, 2012). Predictions of ecosystem behavior, together with plausible future scenarios of land and ecosystem service use, are suitable options for "proactive management", which can be a basis for adaptive management (Nedkov and Burkhard, 2012; Haines-Young et al., 2012).

4. Environmental, social and economic trade-offs

The evaluation of environmental, social and economic trade-offs requires a combined view of how the various ecosystem or landscape function approaches are linked (Bastian et al., 2012). Trade-offs normally occur when the maximization or increase of one ecosystem service results in reduction of other ecosystem services (Busch et al., 2012); this situation regularly arises in multifunctional landscapes (Haines-Young et al., 2012; Scolozzi et al., 2012). Approaches for strategic environmental assessments (Scolozzi et al., 2012) need to be developed to find an optimal balance meeting people's needs (Seppelt et al., 2012; Syrbe and Walz, 2012; Haines-Young et al., 2012).

Proper ecosystem service classification and valuation are needed to evaluate trade-offs (Koschke et al., 2012), taking into account scale peculiarities, synergies and non-accountable services (Busch et al., 2012). Spatially explicit assessments of multiple ecosystem service supply and demand areas provide appropriate information for trade-off evaluation (Syrbe and Walz, 2012; Bastian et al., 2012; Nedkov and Burkhard, 2012; Burkhard et al., 2012). Monitoring schemes especially dedicated to ecosystem services are suggested as a solution for the lack of data, which often hampers appropriate assessments (Burkhard et al., 2012). Benefit transfer and expert evaluation are further possible ways of acquiring data for land cover-related ecosystem service assessments (Koschke et al., 2012). Scolozzi et al. (2012) derived a "surrogate market" for ecosystem services based on a collection of economic values from a literature review, in combination with a Delphi expert survey on ecosystem services to produce spatial ecosystem service representations and assess changes of "potential economic ecosystem service values".

Biodiversity conservation, as well as selected ecosystem service restoration measures, need to consider the potential emergence of ecosystem disservices, causing for example economic losses for farmers (Schneiders et al., 2012). Ecosystem disservices are ecosystem services with negative social or economic effects on human well-being (Bastian et al., 2012), such as hazardous floods assessed in Nedkov and Burkhard (2012).

5. Conclusion "Salzau Message"

Finally, as a synthesis of the presentations and discussions at the "Solutions for Sustaining Natural Capital and Ecosystem Services" conference, the "Salzau Message on Sustaining Ecosystem Services and Natural Capital" has been distilled and signed by the workshop participants (see Box 1). Ecosystem services are truly coming of age, and while there is still much to be done, the possibilities for using this concept to improve and sustain human well-being are enormous. The Ecosystem Services Partnership (ESP) and its growing number of members, will continue to facilitate this movement.

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