Indicators for ecosystem services

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Introduction

An indicator is a quantitative measure which represents a complex system or phenomenon (the indicandum, i.e. the subject to be indicated). Indicators are key elements in policies for goal formulation and evaluation of achievements, as well as simplification of information and communication (cf. Heink and Kowarik, 2010). There is a long tradition of applying indicators in a broad range of different sectors and disciplines working with complex systems from financial markets to health and sustainability science. Indicators are of dual nature: they are both measures (i.e. measurement protocols), and means of communication. This dual nature creates relevant issues in the development and application of indicators.

Indicators as measures

From a natural scientific point of view an indicator can be considered as a measure, which quantifies a relevant property of the indicandum. The relationship between the indicator and the indicandum is of key importance. For an indicator to be 'useful' this relationship needs to be 'close enough', a property which is difficult to formalize in a general way, but which includes aspects of association, monotonity, and low error rates. A further layer of complexity emerges from the fact that as systems are nested, indicator-indicandum relationships can also have nested hierarchies. Accordingly, an indicandum such as diversity, which can be assessed through an ecological indicator such as species richness, can in turn be itself an indicator for the ecological quality of the studied area (Turnhout et al., 2007). For complex systems nested aggregation is a common way of indicator formulation: identifying a set of relevant subsystems/components, quantifying them all, and taking some sort of summary statistic as the overall indicator (Bossel, 2001). Aggregated indicators are often called indices, and this process can create a nested hierarchy of indicators.

According to the measurement theory by Stevens (1946) indicators need to be measured in specific units against a specific scale (e.g. nominal, ordinal, interval, or ratio scale) and linked to a well-specified measurement protocol. Protocols and standardization are thus inherent parts of the indicator development process, which can establish repeatability and ensure data quality. As the name of an indicator can be ambiguous or even misleading in terms of its real content, indicators need to be communicated carefully in inter- and transdisciplinary contexts, keeping references for the underlying structures.

Indicators in a policy context

The main purpose of using indicators in a policy context is to provide messages to stakeholders and policy actors to achieve better (more informed) governance. This involves indicators being used for normative goals in addition to descriptive purposes (Heink and Kowarik, 2010). Hence, not all indicators used are solely science-based. Several major factors that determine the "usefulness" and "success" of an indicator are outside of the scope of science.

The use of scientific information for policy purposes should not be considered as a linear one-way knowledge transfer process. A better model for the relationship of science and policy in this process is that of 'joint knowledge production', which occurs at the science-policy interface, a fuzzy and broad area where

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science and policy overlap (Turnhout et al., 2007, Figure 1). At this interface, knowledge is translated into usable knowledge, and policy questions are translated into research questions. The boundaries of this interface are not sharp in either direction. In this context indicators can be seen as boundary objects (Star and Griesemer, 1989), being accepted by both communities, but having different uses and meanings within them.

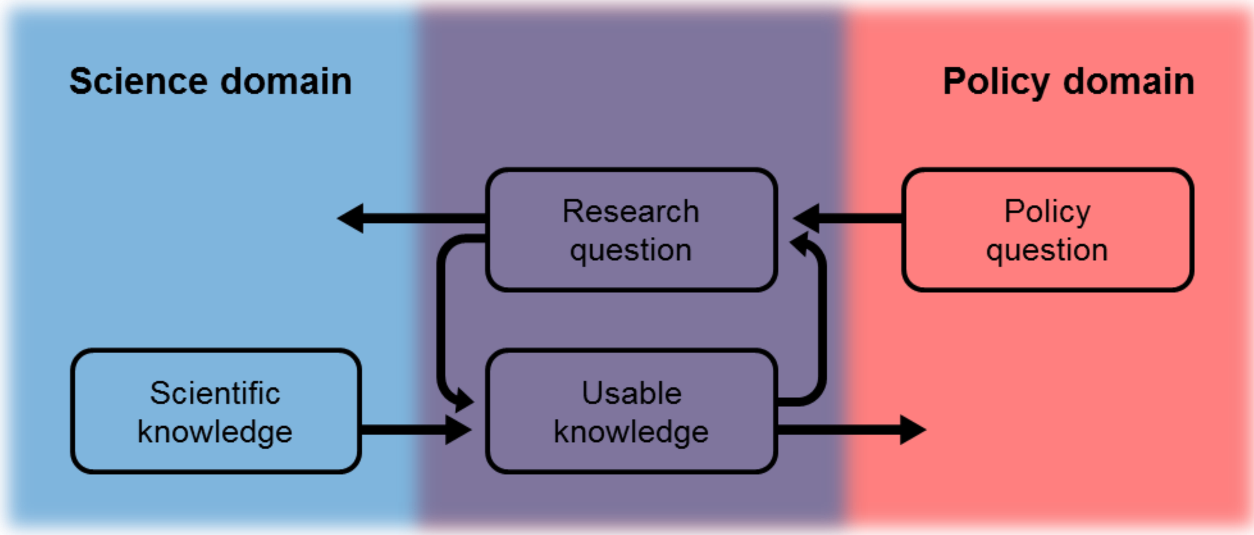

Figure 1. *The conceptualization of the science-policy interface as the sphere of joint knowledge production, where flows of information interact (based on Turnhout et al., 2007).*

Several attempts (e.g. Ritz et al., 2009) to characterise the usefulness of indicators primarily focus on the technical, statistical, and methodological aspects of indicator development. However, from a policy perspective, the success of an indicator resides in its use by policy actors, influence on policy processes, and impact on policy outcomes (Bauler, 2012). It is actually the perception of key stakeholders (policy actors) that determines the uptake of an indicator. According to Eckley et al. (2001) there are three key components determining the success of an indicator: credibility (= scientific and technical believability), salience (= ability to address user concerns), and legitimacy (= the political acceptability or perceived fairness of the development process). In order to become influential, an indicator needs to be perceived simultaneously and consensually as being credible, salient and legitimate by a major group of policy actors (Bauler, 2012). These criteria depend not only on the objective characteristics of the indicator, but on the perceptions of the relevant stakeholders. Accordingly, the process of indicator development should be considered as important as the resulting indicator itself, which is a common characteristic of postnormal science (Funtowicz and Ravetz, 1996). Credibility, saliency, and, particularly, legitimacy can be ensured by thorough stakeholder involvement throughout the indicator development process. Intensive stakeholder involvement can also be considered as an example of extended peer review proposed by Funtowicz and Ravetz (1996). Furthermore, as both individual perceptions and policy arenas evolve, it is also necessary to have 'steering' strategies to continuously redefine and adapt the indicators' underlying institutional processes (Bauler, 2012).

Ecosystem service indicators

Indicators for ecosystem services (ES) have to integrate and balance all general scientific and policy aspects discussed above. There are several systematic reviews for ES assessments which give an overview on various aspects of indicator use in this field (e.g., Feld et al., 2009; Seppelt et al., 2011; Martínez-Harms and Balvanera, 2012; Crossman et al., 2013). Other reviews aim at compiling comprehensive sets of practically applicable indicators for all ES types for policy use (Layke, 2009; Egoh et al., 2012; Maes et al., 2014, 2016). All of these policy-oriented indicator lists include an assessment of the "maturity" of the proposed indicators in terms of data availability and data quality, which greatly improves their usefulness for practical applications.

Problems/Issues to be discussed during the lifetime of OpenNESS

The application of indicators is, in fact, the most straightforward solution for providing policy relevant information on the inherently complex flow of ES from nature to society. The concept of ES is in itself a transdisciplinary boundary object on the margins of natural and social sciences, and policy (see also related SP, Hauck et al., 2016). It is ES indicators that operationalize this scientific object, making it appropriate for conveying simplified messages for policy makers in the form of assessments.

A major challenge specifically relevant to this operationalization process is linking indicators to the ES cascade model (see related SP by Potschin and Haines-Young, 2016). If the cascade framework is considered as a functional systems model describing the flow of services from nature to society, then the different levels of the cascade can be seen as entry points for information through indicators (Figure 2). There is already a conspicuous tendency in the literature for using cascade levels as a template for indicators (e.g. van Oudenhoven et al., 2012; Villamagna et al., 2013; Burkhard et al., 2014; Maes et al., 2014, 2016; Spangenberg et al., 2014; Mononen et al., 2016). In the systematic review of Boerema et al. (accepted in 2016) cascade levels are explicitly linked to the ES indicators, but a detailed analysis on the potential strategies for selecting indicators (and methods) at specific cascade levels is still missing (see also La Notte et al. 2015).

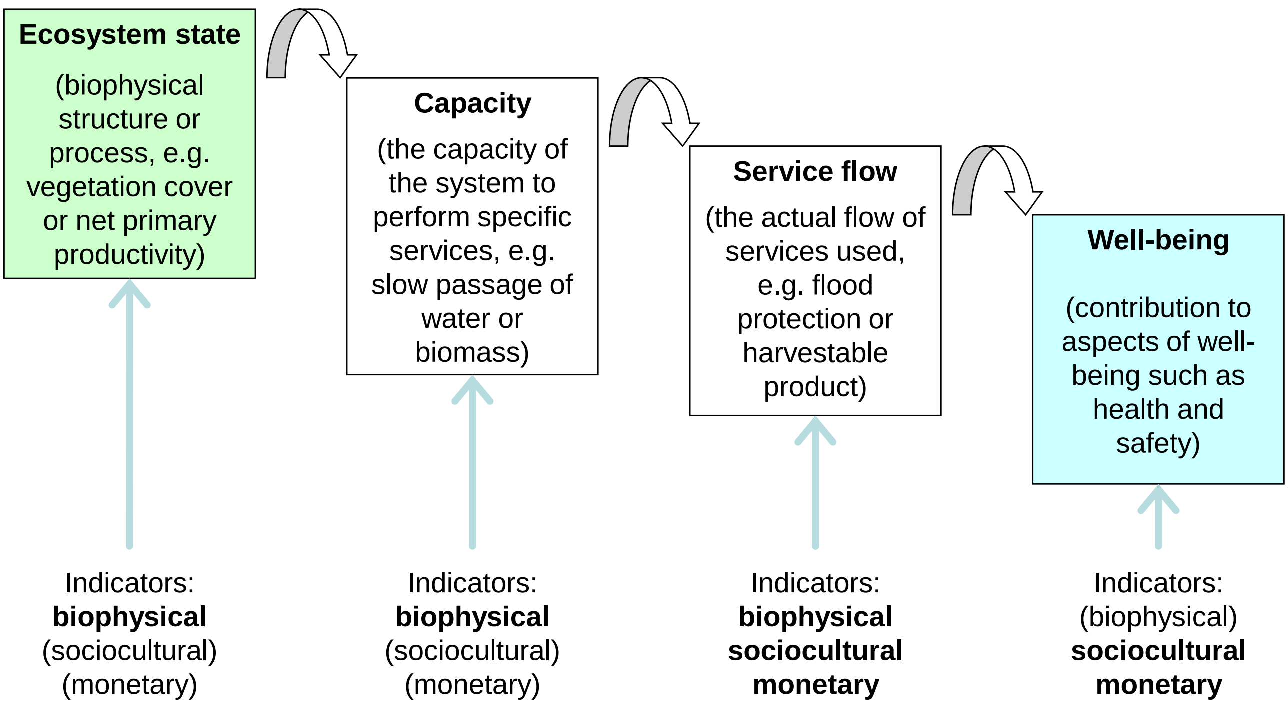

Figure 2. *The ES cascade model as an indicator template (amended from Potschin and Haines-Young, 2011). We reduced the five boxes of the original cascade to four, as in this SP the level "value" is considered to be an indicator of "benefits" (changes in human well-being, see also La Notte et al., 2015).*

The issues discussed above are equally valid for both the biophysical and socio-economic parts of ES assessments. From a technical point of view all quantitative descriptors in relation to ES can be considered as indicators, ranging from tons of carbon dioxide sequestered (indicating e.g. climate stabilization) to market prices. Ensuring good practices of indicator use (e.g., using different names for the indicator and the indicandum, making hidden measurement protocols explicit) seems to be an instrumental objective, which can reduce potential confusion. However, there is still considerable mismatch in the terminology and practices surrounding indicators in the multitude of disciplines connected to ES assessments. Any convergence in language and practices, and the creation of a common integrated framework for ES indicators, as an enhanced boundary object can be mutually beneficial, rendering ES assessments a truly transdisciplinary and operative framework.

Significance to OpenNESS and specific Work Packages[2]

Using indicators constitutes a crucial step in operationalizing the ES concept. Not surprisingly there are several strong links to almost all areas of OpenNESS activities:

WP1 **(Key challenges and conceptual frameworks):** Linking indicators to the individual aspects (Boxes) of the cascade model is a major step in operationalizing the conceptual framework, which can advance the standardisation of ES assessments. (→ Will be addressed in a follow-up project (H2020 ESMERALDA))

WP2 **(Regulatory frameworks and drivers of change):** Indicators can be used to assess governance performance, and ES indicators can be applied to "quantify" scenarios. (→ Partly addressed by the ScenQuant tool developed by MTA ÖK during OpenNESS)

WP3 **(Biophysical control of ecosystem services):** The fundamental products of WP3 tools are actually biophysical indicators. Any conceptual developments on indicator use are of great relevance for WP3. (→ Partly addressed in D3.1 and the subsequent analysis of the resulting database)

WP4 **(Valuation of the demand for ecosystem services):** Integrating socio-economic indicators into a common indicator framework can induce fruitful discussions and enhance transdisciplinarity. A major challenge is the normative justification of indicator scores (e.g. by establishing social norm curves, e.g. Smyth et al., 2007).

WP5 **(Place-based exploration of ES and NC concepts):** The application of indicators is a core element of the local/regional assessments performed in the case studies. Any conceptual guidance and harmonization of approaches can be extremely beneficial to their work. (→ Will be addressed in the combined deliverable D3.3-4.4)

WP6-7 **(Integration: Synthesis and Menu of Multiscale Solutions and (Impact and Dissemination):** Indicators are communication tools which should be developed while involving stakeholders. Aspects of indicator use are particularly relevant for the menu of multiscale solutions and Oppla.

Relationship to four challenges[3]

Human well-being: Indicators at the fourth level of the cascade can explore the dimensions of HWB. More conceptual work is needed on the dimensions other than monetary wealth. Applying a consistent system of indicators helps to develop a detailed and	**Sustainable Ecosystem Management:** Quantifying NC and ES in different geographical, environmental and management contexts may help to measure structures and processes, as well as improve management planning, providing decision support for a

2 For a brief description of the OpenNESS Work Packages see: http://openness-project.eu/about/work-packages

3 There are certainly more societal challenges; the reduced number presented here is due to the four major challenges mentioned in the work programme of FP7 to which OpenNESS responded.

quantitative insight into the way natural capital (which can also be conceptualized using indicators along the cascade) and service flows exert influence on well-being.	sustainable flow of services. Measuring the same indicator over time can provide an overview of the sustainability of the system/ES.
Governance: Ensuring credibility, salience and legitimacy for all major stakeholder groups is necessary for policy influence. This can be achieved by thorough stakeholder involvement in the development and use of indicators. New participatory and transdisciplinary models for developing biophysical indicators should be actively sought.	**Competitiveness:** Inconsistencies between local capacities and actual use, as well as spatial lags between sources and beneficiaries can be explored using indicators. These factors can add relevant insights into regional competitiveness studies.

Recommendations to the OpenNESS consortium:

- The selection / construction of ES indicators should be an open and transparent process with a high level of stakeholder involvement. Aspects of credibility, salience and legitimacy should be actively observed and managed.
- The ES cascade framework can successfully be used as a template for indicator development and use, much better adapted for ES studies than other common frameworks (e.g. DPSIR[4]). OpenNESS with its case studies has a wide range of possible applications for operationalizing the ES concept through the use of indicators along the cascade.
- All aspects of indicator use (indicandum, protocol) should be handled consciously in the ES quantifications / valuations works of the case studies.

Suggested three "must read" papers

Heink, U. and I. Kowarik (2010): What are indicators? On the definition of indicators in ecology and environmental planning. *Ecological Indicators* **10(3)**: 584–593.

Turnhout, E. et al. (2007): Ecological indicators: Between the two fires of science and policy. *Ecological Indicators* **7(2)**: 215–228.

Maes J, et al. (2016): An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. *Ecosystem Services* **17**: 14-23

Further cited papers

Bauler, T. (2012): An analytical framework to discuss the usability of (environmental) indicators for policy. *Ecological Indicators* **17**: 38–45.

Boerema, A., et al. (accepted): Are ecosystem services adequately quantified? *Journal of Applied Ecology*, http://doi.org/10.1111/1365-2664.12696

Bossel, H. (2001): Assessing viability and sustainability: a systems-based approach for deriving comprehensive indicator sets. *Conservation Ecology* **5**(2): 12.

Burkhard, B., et al. (2014): Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification. *Landscape Online* **34**:1-32

Crossman, N. D., et al. (2013): A blueprint for mapping and modelling ecosystem services. *Ecosystem Services* **4**: 4-14.

[4] The "Driving forces - Pressures - State - Impact – Responses" framework of the European Environmental Agency, http://ia2dec.pbe.eea.europa.eu/knowledge_base/Frameworks/doc101182

Eckley, N. et al. (2001): *Designing effective assessments: the role of participation, science and governance, and focus*. Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University. Available at: http://www.unep.org/DEWA/water/MarineAssessment/reports/germany_report/EEA-report-issue_26.pdf (accessed 02.12.2015)

Egoh, B. et al. (2012): *Indicators for mapping ecosystem services: a review*. EU Publications Office, Luxembourg. 113 pp.

Feld, C.K. et al. (2009). Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales. *Oikos* **118(12)**: 1862–1871.

Funtowicz, S.O. and J.R. Ravetz (1996): Risk management, post-normal science and extended peer communities. In: Hood, C.J., Jones, D.K.C. (Eds.), *Accident and Design, Contemporary Debates in Risk Management*. UCLL Press.

Hauck, J. et al. (2016): Ecosystem Services and Transdisciplinarity. In: Potschin, M. and K. Jax (eds): *OpenNESS Ecosystem Service Reference Book*. EC FP7 Grant Agreement no. 308428. Available via: www.openness-project.eu/library/reference-book

La Notte, A. et al. (2015): An ecological-economic approach to the valuation of ecosystem services to support biodiversity policy. A case study for nitrogen retention by Mediterranean rivers and lakes. *Ecological Indicators*, **48**: 292–302.

Layke, C. (2009). Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators. WRI Working Paper. World Resources Institute, Washington DC. 36 pp.

Maes, J. et al. (2014): Mapping and Assessment of Ecosystems and their Services: Indicators for ecosystem assess-ments under Action 5 of the EU Biodiversity Strategy to 2020. 2nd Report. EU Publications Office, Luxembourg. 81 pp.

Martínez-Harms, M. and P. Balvanera (2012): Methods for mapping ecosystem service supply: a review. International *Journal of Biodiversity Science, Ecosystem Services & Management* **8**: 17-25.

Mononen, L. et al. (2016): National ecosystem service indicators: Measures of social–ecological sustainability. *Ecological Indicators* **61**: 27-37.

Potschin, M. and R. Haines-Young (2011): Ecosystem Services: Exploring a geographical perspective. *Progress in Physical Geography* **35(5)**: 575-594.

Potschin, M. and R. Haines-Young (2016): Conceptual Frameworks and the Cascade Model. In: Potschin, M. and K. Jax (eds): *OpenNESS Ecosystem Services Reference Book*. EC FP7 Grant Agreement no. 308428. Available via: www.openness-project.eu/library/reference-book

Ritz, K., et al. (2009): Selecting biological indicators for monitoring soils: a framework for balancing scientific and technical opinion to assist policy development. *Ecological Indicators* **9(6)**: 1212–1221.

Saarikoski, H. et al. (2015): Exploring operational ecosystem service definitions: The case of boreal forests. *Ecosystem Services*, **14**: 144–157.

Seppelt, R. et al. (2011): A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* **48(3)**: 630–636

Smyth, R.L. et al. (2007): Defining acceptable levels for ecological indicators: an approach for considering social values. *Environmental Management* **39**: 301–315.

Spangenberg, J. H. et al. (2014). The ecosystem service cascade: Further developing the metaphor. Integrating societal processes to accommodate social processes and planning, and the case of bioenergy. *Ecological Economics* **104**: 22–32.

Star, S. L. and J.R. Griesemer (1989): Institutional ecology, translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science* **19(3)**: 387–420.

Stevens, S. S. (1946). On the Theory of Scales of Measurement. *Science* **103**: 677–680.

van Oudenhoven, A.P.E. et al. (2012). Framework for systematic indicator selection to assess effects of land management on ecosystem services. *Ecological Indicators* **21**: 110-122

Villamagna, A.M. et al. (2013): Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity*: **15**: 114–121.

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