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Short Communications

An operational framework for integrated Mapping and Assessment of Ecosystems and their Services (MAES)

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Abstract

Mapping and Assessment of Ecosystems and their Services (MAES) are central to the EU Biodiversity Strategy to 2020. Action 5 of the Strategy's second target asks all EU member states to map and assess the state of ecosystems and their services in their national territories. Such comprehensive mapping and assessment builds on several individual tasks and their systematic integration. Therefore, an integrated and operational framework is needed, supporting and coordinating these activities. The presented framework builds on existing work done by the European Commission's MAES Working Group and provides a clear nine-step approach including the identification of relevant questions or themes to be addressed, identification and mapping of ecosystem types, ecosystem condition and ecosystem services, their integration and dissemination of results. This framework can be used to set-up related research and development initiatives and to guide involved scientists, decision-makers and practitioners through the different steps and related tasks of the process.

Keywords

ecosystem services, MAES, integrated assessment, stakeholder, EU policy

Background

Ecosystem Services (ES) have a high potential for application in policy and decision making (Costanza et al., 2017). Before that, ES need to be quantified in an integrated manner, across domains of biophysical, social and economic methods and on different spatiotemporal scales. All ES are spatial phenomena, thus mapping them makes sense (Burkhard and Maes 2017, Burkhard et al. 2012a).

The European Union's (EU) Biodiversity Strategy to 2020 aims under its Target 2 to maintain and enhance ES in Europe. To this end, the European Commission is developing a knowledge base on ecosystems (Maes et al. 2012). Action 5 of the Strategy is the legal basis for this knowledge base. It foresees that EU Member States, together with the European Commission, will map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at national and EU level by 2020.

The Working Group on Mapping and Assessment on Ecosystems and their Services (MAES) is mandated to co-ordinate and oversee Action 5. In 2012, the Working Group developed ideas for a coherent analytical framework to ensure that consistent approaches are used. The report, adopted in April 2013, proposed a conceptual framework linking biodiversity, ecosystem condition and ecosystem services to human well-being. Furthermore, it develops a typology for ecosystems in Europe and promotes the use of the Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin 2013, Maes et al. 2016b). In a next step, this framework was further developed by providing guidance and indicators. Practical guidance has been provided through a common assessment framework (page 22 in Maes et al. 2014) while a selection of indicators has been proposed to map and assess ecosystem condition and ES.

This paper builds on the MAES common assessment framework and reorganises it in a number of practical steps to be followed to ensure an integrated result. The MAES conceptual model (page 17 in Maes et al. 2013) is based on the premise that the delivery of certain ES, upon which we rely for our socio-economic development and long-term human well-being, is strongly dependent on both the spatial accessibility of ecosystems as well as on ecosystem condition. This hypothesis has been translated into a structure to guide the ecosystem assessment work as required by Action 5: (i) Mapping of ecosystems; (ii) Defining the condition of the ecosystem; (iii) Quantification of the services provided by the ecosystem; and (iv) Compilation of these into an integrated ecosystem assessment.

This paper enhances the operational guidance of the MAES common assessment framework by providing nine steps which ensure the delivery of an integrated ecosystem assessment at EU and national levels. The paper contributes to the objectives of the ESMERALDA project*2, a Support and Coordination Action (SCA) funded under the European Commission's Horizon 2020 funding scheme with the specific aim of supporting the implementation of Action 5 in EU Member States. The framework delivered in this paper can be used to specifically guide the integrated assessment of the state of ecosystems and their services in the EU which is foreseen in 2019 in the framework of the MAES initiative (Maes et al. 2018). In addition, ESMERALDA will deliver a framework for integrated ecosystem assessment which can be used in a broader policy context and which aims to integrate ecosystems and their services in design and implementation of policies.

The framework

The operational framework for integrated MAES that is proposed is composed of nine consecutive steps:

- Step 1: Question and theme identification;
- Step 2: Identification of ecosystem types;
- Step 3: Mapping of ecosystem types;
- Step 4: Defining ecosystem condition and identification of ES delivered by ecosystems;
- Step 5: Selecting indicators for ecosystem condition and ES;
- Step 6: Ecosystem condition and ES indicator quantification;
- Step 7: Mapping ecosystem condition and ES;
- Step 8: Results integration; and
- Step 9: Dissemination and communication of results.

Step 1 refers to clearly defined questions that should be addressed, this being key to successful implementation of ES in decision-making (Rosenthal et al. 2014). Steps 2-3 refer to ecosystem types, steps 4-7 deal with mapping and assessment of ecosystem condition and ES. Steps 8-9 finally integrate, disseminate and communicate the outcomes of the mapping and assessment. Relevant stakeholders should optimally be involved in each of the nine steps. The authors have, however, indicated the minimum stakeholder involvement needed for successful implementation of MAES (Fig. 1).

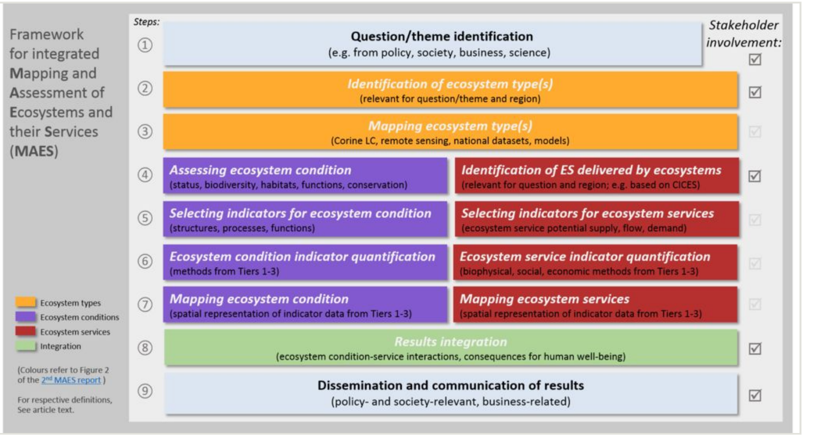

Figure 1.

Framework for integrated Mapping and Assessment of Ecosystems and their Services (MAES). Colours and basic structure refer to Figure 2 of the 2nd MAES report (Maes et al. 2014).

Definitions of terms used in the framework can be found in Table 1

Table 1.

Definitions for terms used in the framework (based on Maes et al. 2016a, Maes et al. 2013, Maes et al. 2016b, Potschin and Burkhard 2015, ESMERALDA 2015, EEA 2016).

Term	Definition
Assessment	The analysis and review of information derived from research for the purpose of helping someone in a position of responsibility to evaluate possible actions or think about a problem. Assessment means assembling, summarising, organising, interpreting and possibly reconciling pieces of existing knowledge and communicating them so that they are relevant and helpful to an intelligent but inexpert decision-maker. Predominantly, scientific evidence is translated into information that is understandable for policy and decision-making, e.g. through maps, indicators, narratives and graphs.
Integrated assessment	Integrates data and information on biophysical ecosystem components with socio-economic system components and the societal and policy contexts in which they are embedded. Links between ecosystem condition, habitat quality and biodiversity, how they affect the ability of ecosystems to deliver ecosystem services and then evaluating the consequences for human well-being are assessed.
Ecosystem condition	A description of the structure or functioning of an ecosystem according to some predefined criteria. Relates to the capacity of an ecosystem to yield services.
Ecosystem (service) mapping	Spatial delineation of ecosystems as well as their condition and the services they supply through the spatial integration of a wide range of data sets. The different mapping approaches and techniques are embedded in the integrated and consistent assessment framework.

Term	Definition
Tiered approach	A flexible mapping and assessment approach from simple (Tier 1) to complex (Tier 3) methods, combining less sophisticated, expert- and land cover-based approaches and the use of existing ES indicator data, with more complex and comprehensive modelling frameworks.

In the following, each individual step will be described in more detail:

Step 1. Question and theme identification (from policy, society, business and science)

Every ecosystem assessment has to be relevant to a certain theme and address a broad range of questions pertaining to decision-making processes which occur at different levels of decision-making and across different actors of society. If not, it may simply end up in a library. MAES-relevant actors include policy-makers (on EU, national, regional and local levels), the society (EU as a whole, individual member state citizens or groups of citizens, regions and municipalities, NGOs), business people (companies, land users) and science (as developers and users of MAES-related products). A first list of 12 policy questions can be found in Maes et al. 2013, but the list will be revised in subsequent work.

Step 2. Identification of ecosystem types

One would expect that an ecosystem type is more than land cover and land use categories. Ecosystems are dynamic complexes of plant, animal and micro-organism communitiesand their non-living environment interacting as a functional unit. In practice, ecosystem classifications are enhanced land cover maps and include additional information about for instance the soil, the climate and the vegetation to come to a more detailed identification of ecosystems types. Thus, ecosystems within each category share a set of climatic, geophysical and biochemical conditions, biological conditions (including species composition and interactions) and socio-economic factors shaping land cover (as dominant uses by humans tend to differ across ecosystems) (Maes et al. 2013). The classification of ecosystems types is important for many ecosystem functions, for instance the breeding and feeding of birds, which requires different neighboring ecosystems or mosaics of cropland, grassland and forests that are more attractive for recreation than uniform landscapes. In EEA 2016), a classification of ecosystem types for the European Union based on enhanced land cover is provided. To develop an agreed typology (classification) of ecosystems, it is necessary to know first the purpose of the mapping, the required scale and the data availability. The ecosystem typology for mapping proposed by EEA 2016) provides a framework that can be used as a basis or reference for the identification of ecosystem types for the needs of the EU Biodiversity strategy. Its hierarchy is developed at a first and a second level, which can be aggregated at the European scale. The further classification on third and fourth levels can be developed specifically for the individual EU member states in order to reveal the country specifics. A classification at third level has, for example, been developed and applied for urban ecosystems in Bulgaria (Nedkov et al. 2017). It is based on the National Concept for Spatial Development in Bulgaria and the classes are defined in correspondence with the EUNIS habitat classification*1.Blasi et al. 2017) proposed an ecosystem map for the implementation of the EU Biodiversity strategy in Italy which contains 84 ecosystem types.

Step 3. Mapping of ecosystem types

Ecosystem mapping is increasingly being undertaken at a variety of scales and for various purposes. It is a powerful tool for decision-makers that can be used as a communication tool to initiate discussions and engagement with stakeholders (Erhard et al. 2017). Once a typology of ecosystems has been defined, the next step is to map their spatial extent based on their biotic and abiotic characteristics. The map can be compiled and the underlying spatial data can be analysed using Geographical Information System (GIS) techniques, for instance to provide statistical information on the spatial extents and distribution of the different ecosystem types. For example, a map of ecosystem types on the European scale has been produced by combining maps of CORINE land cover with the EUNIS habitats database (EEA 2016). Despite uncertainties implied in the delineation of ecosystems using spatially explicit units (as explained in EEA 2016), these types of maps are an important contribution to conservation objectives, such as assessing the degree to which different ecosystems are covered by protected area networks. The delineated ecosystem types can also be used as spatial units for the assessment of selected ES. They can for example be regarded as Service Providing Units (SPUs; Burkhard and Maes 2017). This is valid especially for provisioning ES such as crops or timber production, which are directly associated with agricultural and forest ecosystems respectively.

Step 4a. Defining ecosystem condition

An assessment of the condition of the various ecosystem types requires information about drivers, mainly land/sea use and management and pressures such as land-take, fragmentation, biodiversity loss, invasive species, pollution and climate change as well as their impacts on the structure and function of each ecosystem type.

An important part of this step is to define what ecosystem condition is. Ecosystem condition for the purpose of MAES is the physical, chemical and biological condition of an ecosystem at a particular point in time. The Millennium Ecosystem Assessment described ecosystem condition as the capacity to provide ES. In relation to natural capital accounting, ecosystem condition reflects the overall quality of an ecosystem asset, in terms of its characteristics (System of Environmental-Economic Accounting - Experimental Ecosystem Accounting (SEEA-EEA)). Specific definitions of ecosystem condition can be elaborated for each ecosystem type, for instance by making explicit reference to policy targets such as achieving favourable conservation status of protected habitats or achieving water quality targets.

Importantly, assessing ecosystem condition also requires a baseline or a reference against which the current condition can be evaluated. This can be a point in time or space where undisturbed ecosystem condition prevails. In cases where neither pristine condition nor historical references can be found, statistical approaches and expert judgement can be used to set the reference. However, in many cases, reference conditions are difficult to define and proposals result in substantial scientific debate. It is particularly difficult to define reference conditions in social-ecological systems where people and ecosystems have closely interacted over several thousand years to co-produce ES (Jones et al. 2016). As an alternative, a baseline situation can be used to assess and compare the current conditions of ecosystems in order to detect further deterioration or improvements. Concepts such as ecological integrity (Müller 2005) and ecosystem health (Rapport et al. 1998) help to identify and describe key elements of ecosystem condition and to understand their interactions.

Step 4b. Identification of ES delivered by ecosystems

The questions (from Step 1), as well as stakeholders involved in the process, drive the selection of ES to be included in the assessment. Different ecosystems deliver different ES with different quantities and qualities. There are also however substantial differences in ES supply depending on land use, climate or environmental condition. A list with essential ES which should be part of the assessment can be drawn from available global ES classifications and adapted according to specific needs or the specific context. EU MAES-type assessments are usually based on CICES, which provides a very comprehensive ES classification in five hierarchical levels. Four of them (section, division, group, class) are precisely defined while the fifth level (class type) is open. Many class types can potentially be recognised and nested in the higher level classes, depending on the ecosystems being considered (Haines-Young and Potschin 2013). This enables selection and further division of ES according to the specific needs of the study and scale.

Step 5a. Selecting indicators for ecosystem condition

Following the rather broad definition of ecosystem condition in step 4a, indicators for ecosystem condition are likely to describe the abiotic and biotic quality of ecosystems (Erhard et al. 2017). The abiotic or environmental quality is usually indicated by soil, water and air quality in terms of their chemical composition. The biotic quality of an ecosystem is often described by structural metrics such as the presence or abundance of particular species, the composition of communities or the physical structure of ecosystems as well as by functional metrics such as certain ecological processes (Jørgensen et al. 2013Palmer and Febria 2012). Biodiversity is a key factor for the supply of many ES. Concepts such as Essential Biodiversity Variables (EBV) can help to systematically select appropriate indicators covering relevant aspects of biodiversity and to link them to ecosystem condition (Haase et al. 2017). Ecosystem structures and functions are different in terrestrial, freshwater, coastal and marine ecosystems. Therefore, specific indicators need to be selected that represent the peculiarities of respective ecosystem types.

Both structures and functions define the capacity of the ecosystem to provide ES. Usually ecosystem condition indicator frameworks also include information about the pressure on ecosystems (e.g. deposition of nitrogen or habitat fragmentation), as they would allow policy and decision-makers or ecosystem managers to take action.

Step 5b. Selecting indicators for ecosystem services

A complete understanding of the flow of ES from ecosystems to society entails a set of indicators which describes three aspects: the potential of ecosystems to provide a sustainable flow of services, the demand for services by beneficiaries and the actual use of the service (Burkhard and Maes 2017). The ecosystem services 'cascade' (Haines-Young and Potschin 2012) can be used to organise ES indicators along these different aspects.

The flow of services from ecosystems as benefits to people neither come for free nor by themselves. ES, in order to be beneficial and valuable to humans, normally require additional investments from other types of capital (Burkhard et al. 2012b). The energy, water and matter contents of ES are therefore, in almost all cases, a combination of natural (ecosystem processes-based) components and human-based inputs. Therefore, these anthropogenic inputs could also be part of an ES indicator set. Grunewald et al. 2017) proposed a set of indicators for four ES (fibres and other materials, flood protection, mass stabilisation and experiential use of plants animas and land-/seascape) which were implemented at national scale in Germany and contain both natural (e.g. forest area, green space) and anthropogenic (e.g. development of annual logging, proportion of built-up areas) components.

Step 6a. Ecosystem condition indicator quantification

Ecosystem condition indicators are ideally quantified based on field measurements or through (monitoring) datasets which store such measurements. Structural indicators can usually be measured using single-point-in-time measurements whereas functional indicators depend on at least two measurements in time. Examples include measurements of the concentration of nitrogen in rivers or field observations of iconic species such as salmon. Additionally to direct measurements, process-based modelling and GIS techniques provide possibilities to extrapolate and further analyse existing datasets.

Aggregation methods are available to combine several indicators or metrics into single indicators or sets of indicators which can be used to capture the condition of an ecosystem in a reduced number of indicators or quality scores (Müller 2005).

Step 6b. Ecosystem service indicator quantification

A variety of biophysical, economic and social methods exists to quantify ES indicators (Chapter 4 in Burkhard and Maes 2017). Biophysical methods map ES supply, use or demand as stocks or flows in physical units (such as ha, kg, m^3). They can be based on observations (field measurements or remote sensing) or on ecological and biophysical models. Economic methods quantify and assess economic or monetary ES values, social-cultural methods seek to assign non-monetary values to ES. The selection of the appropriate method for each indicator depends on the specifics of its measurement, data availability and the scale and purpose of the study. A tiered approach (Table 1) helps to find respective methods.

Step 7a. Mapping ecosystem condition

Ecosystems are impacted by different pressures. They broadly fall into five categories (HIPOCO): Habitat and land conversion, Introductions of invasive alien species, Pollution and eutrophication, Overexploitation, Climate change and Others (e.g. soil erosion). These pressures on ecosystems vary in time but also in space. Consequently, ecosystem condition is variable across the landscape and mapping of condition is needed to understand how ES capacities spatially change or where mitigation actions need to take place.

However, since the quantification of ecosystem condition is so dependent on measurements (Step 6a), maps of ecosystem condition are not readily available and resource-intensive to produce, in particular for larger areas. This contrasts with ES mapping (step 7b), for which frequently computer-based models are applied in case direct or indirect observations are not available. Data collections based on monitoring networks across countries for mapping air and water quality are usually available and can be used for mapping ecosystem condition. Presence or absence data for species which are used in ecosystem condition assessments are available as well, butthese have not usually been sampled using harmonised protocols, thus limiting the applicability for mapping.

As an alternative, pressures on ecosystems (see above) can be used as proxies for mapping because there is often a direct (negative) relationship between pressures and condition (EEA 2016).

Step 7b. Mapping ecosystem services

ES maps quantify and visualise where and to what extent ecosystems contribute to human well-being (Burkhard and Maes 2017). ES maps thus operationalize the ES framework and related concepts. To understand ES provision in a spatial context, there is a need to identify both where ES are generated and where they are used. Accordingly, several methods have been developed to map ES supply (or potential), ES use and demand for ES (Burkhard et al. 2012a)

Integrated mapping approaches typically follow a tiered approach (Table 1), starting from maps derived from, for instance, land cover or land use datasets which serve as a basis to add more detailed information about ecosystem functioning or expert-based knowledge about ecosystems. There is a growing number of methods, tools and decision support systems which can be used to map ES. They can be consulted in Burkhard and Maes 2017. Key components for high quality ES maps are scientific accuracy, reproducibility and credibility. This can be achieved by incorporating stakeholder knowledge, by the use of common mapping standards and by improving our systems to monitor ES.

Step 8. Results integration

An integrated ecosystem assessment considers the condition of ecosystems as well as their capacity to deliver ES and to contribute to human well-being. Thus, it first brings together two ecosystem assessment approaches and then links the results to human well-being in the sense of complex interlinked Social-Ecological Systems (SES). The ecosystem assessment approaches are based on first assessing the condition or state of an ecosystem based on its similarity with a least-impacted, reference or historical state (e.g. ecological status assessments of the EU Water Framework Directive (WFD)). This is based on indicators such as species richness, pollutant concentration or habitat fragmentation. The second approach measures the performance of ecosystems by evaluating the level of ES they provide to humans (such as the amount of drinking water, pollutant removal or carbon sequestration).

In the context of MAES, results integration needs to combine the knowledge on ecosystem condition and ES to address key questions. Some examples are: Are Europe's ecosystems in good shape to continue delivering essential ES? What is the relationship between ecosystem condition and ES delivery? How can we use information on ecosystem condition and services to help prioritise restoration of degraded ecosystems?

Step 9. Dissemination and communication of results

The integrated ES mapping and assessment results should be relevant and helpful not only to the ES community, but also to an intelligent but usually inexpert decision-maker. Therefore, they need to be translated into information that is understandable for decision-makers from policy, business and society. In order to prepare the maps and other assessment materials for effective dissemination and communication, it is necessary to define several questions such as: What level of decision-making is intended to be reached? Which decision making body should be addressed? What spatial and temporal scale this body is responsible for? What are the concrete questions to be addressed? When the answers of these questions are found, the specific needs of the decision makers should be analyzed. Klein et al. 2015) proposed a demand analysis to identify user demands for ES information. The results of their survey was highly heterogeneous. However, they managed to identify five main recommendations: (1) 3D landscape visualisations are preferred for analysing and exploring ES-related information; (2) texts and abstracts are preferred for communication and discussion support; (3) thematic 2D map representations are preferred to support scenario development in public applications; (4) abstract 3D landscape visualisations facilitate estimations in group applications; and (5) charts and tables, in combination with thematic 2D map representations, support analyses (Klein et al. 2015).

Conclusions

The presented framework provides a structure to guide integrated mapping and assessment of ecosystems and their services. Its linear step-wise structure facilitates the development of respective studies, starting from relevant questions to be answered and leading to the communication of integrated results. The authors are aware that such a linear approach may not cover all aspects, interrelations and feedbacks in complex social-ecological systems. ES are a truly transdisciplinary field of research and application and the involvement of stakeholders is mandatory if the assessment is to be successful. The authors, however, rather want to provide an easy-to-comprehend and applicable multi-tiered approach, considering different ES quantification and mapping methods (biophysical, social-cultural and economic) that can be applied according to specific needs, data and resources availability.

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Endnotes

*1 https://eunis.eea.europa.eu/

*2 http://www.esmeralda-project.eu/