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An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020

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ABSTRACT

In the EU, the mapping and assessment of ecosystems and their services, abbreviated to MAES, is seen as a key action for the advancement of biodiversity objectives, and also to inform the development and implementation of related policies on water, climate, agriculture, forest, marine and regional planning. In this study, we present the development of an analytical framework which ensures that consistent approaches are used throughout the EU. It is framed by a broad set of key policy questions and structured around a conceptual framework that links human societies and their well-being with the environment. Next, this framework is tested through four thematic pilot studies, including stakeholders and experts working at different scales and governance levels, which contributed indicators to assess the state of ecosystem services. Indicators were scored according to different criteria and assorted per ecosystem type and ecosystem services using the common international classification of ecosystem services (CICES) as typology. We concluded that there is potential to

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Natural Capital

develop a first EU wide ecosystem assessment on the basis of existing data if they are combined in a creative way. However, substantial data gaps remain to be filled before a fully integrated and complete ecosystem assessment can be carried out.

1. Introduction

In 2011 countries which are party to the Convention of Biological Diversity (CBD) adopted a new strategic plan until 2020. This plan includes the so called Aichi biodiversity targets, 20 ambitious objectives to stop biodiversity loss and to ensure healthy ecosystems providing essential services to people. Following the adoption of this global strategic plan, the European Union (EU), which also signed the CBD, proposed a European Biodiversity Strategy to 2020 (European Commission, 2011). This strategy includes six targets. They cover the full implementation of the EU nature legislation, a better protection of ecosystems and the services they provide, more sustainable agriculture and forestry, better management of fish stocks, tighter controls on invasive alien species, and a bigger EU contribution to averting global biodiversity loss. Target 2, in particular, aims to maintain and enhance ecosystems and their services by establishing green infrastructure and restoring at least 15% of degraded ecosystems. To meet the targets the Biodiversity Strategy sets 20 actions. Three concrete actions are proposed to achieve target 2. Action 5 improves the knowledge base on ecosystems and ecosystem services; Action 6 sets priorities to restore ecosystems and promote the use of green infrastructure; Action 7 launches an initiative to ensure the no net loss of biodiversity and ecosystem services.

Under Action 5 the Member States of the EU are committed to map and assess the ecosystems and their services on their national territory. 'Mapping' stands for the spatial delineation of ecosystems as well as the quantification of their condition and the services they supply. Ecosystems are spatially explicit and so, too, are the pressures and impacts upon them. As a result the condition of ecosystems and the supply of ecosystem services are expected to be spatially heterogeneous as well, requiring the use of spatial data and indicators (Maes et al., 2012). 'Assessing' refers to the translation of this predominantly scientific evidence into information that is understandable for policy and decision making, e.g. through maps, indicators, narratives and graphs.

The commitment of Action 5, together with other commitments formulated in the Biodiversity Strategy, was formally adopted by the Council of the EU and endorsed by the European Parliament, two institutions that share decision power. This gives the European Commission, which is the executive arm of the EU, a strong mandate to implement Action 5. In practice, the implementation of the mapping and assessment of ecosystems and their services (MAES) is in the hands of an expert working group. The working group MAES consists of official representatives of EU Member States, experts affiliated to different European Commission services and of the European Environment Agency, as well as independent scientists. The MAES working group has been set up within the Common Implementation Framework of the Biodiversity Strategy and it reports back to the Co-ordination Group for Biodiversity and Nature (CGBN), which oversees the implementation of biodiversity policy in the EU. The working group meets two or three times per year with the aim to provide the best available guidance to Member States on how to map ecosystems, and assess their state and the services they provide.

The essential challenge of Action 5 and of the working group is thus to make the best use of and to operationalize the information and scientific knowledge currently available on ecosystems and their services in Europe. Consequently, Action 5 and MAES build strongly on the outcomes of the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010) studies. Importantly, some countries in Europe have started or recently finished a national ecosystem assessment or national TEEB studies, for example the United Kingdom (UKNEA, 2011) and Spain (Santos-Martín et al., 2013).

This paper aims to describe the policy process and the technical results attained so far in the development of an indicator framework for ecosystem assessment in the EU (under Action 5 of the Biodiversity Strategy). It is the result of a collaborative effort from stakeholders working at different scales. This paper describes the working process and summarized the most relevant initial outcomes: (i) a conceptual framework linking biodiversity, ecosystem state and ecosystem services to human well-being; (ii) a typology for ecosystems in Europe; and (iii) a typology for ecosystem services. In a second phase, the typologies were tested through four thematic pilot studies (Maes et al., 2014). These pilot studies considered Europe's main ecosystem types: croplands, grasslands, forests, rivers and lakes, wetlands, and four marine ecosystems. Also ground waters were included in one of the thematic pilots. Finally, we summarized the results of the pilot studies into a single set of indicators which can be seen as a first European-wide agreed indicator frame for mapping ecosystems and their services.

2. A conceptual framework for ecosystem assessment in the EU

Driven by a set of policy questions, which are listed in the supplementary material of this paper (Supplement 1), the working group MAES developed a conceptual framework with the aim to provide support to future assessments by EU Member States. The first versions of the conceptual model were rooted in the ecosystem services cascade model (Haines-Young et al., 2012; Haines-Young and Potschin, 2010), the TEEB framework (de Groot et al., 2010), and the UK National Ecosystem Assessment (UKNEA, 2011). It also contained elements of the DPSIR framework (Drivers-Pressures-State-Impact-Response) linked to the cascade model (Kandziora et al., 2013). The DPSIR approach has traditionally been used in the conception and implementation of environmental legislation in Europe (Niemeijer and de Groot, 2008). The cascade model and its revised version adopted by the TEEB study connect ecosystem structure and ecosystem functioning to human well-being through the flow of ecosystem services (de Groot et al., 2010). However, further modifications to the conceptual framework were needed due to the particular European governance context. The Biodiversity Strategy is a non-binding communication and cannot be enforced as for instance a directive. It follows that finding consensus among the different Member States of the EU is crucial to achieve desired policy outcomes. Some Member States preferred that a conceptual model emphasized the supply side of ecosystem services. They insisted focusing particularly on the proper functioning of ecosystems and the role of biodiversity in underpinning ecosystem services. Others states preferred a more profound emphasis on the demand site of ecosystem services with

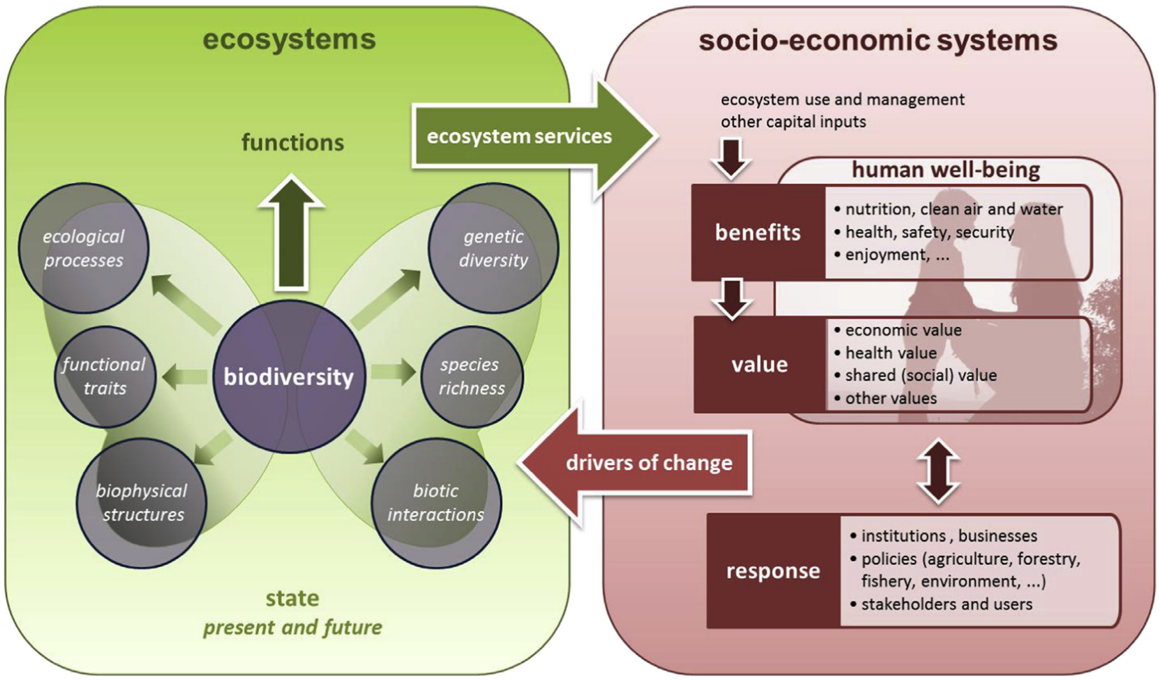

Fig. 1. Conceptual framework for EU and national ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020.

additional focus on unravelling the benefits and values that arise from ecosystem services. These differences among Member States are driven by different motivations. An emphasis on state and functions of ecosystems and biodiversity, which underpin the supply of ecosystem services, can be closely aligned with present reporting obligations under for instance the Habitats Directive. Existing knowledge is thus framed in the new concept of ecosystem services. An emphasis on benefits and values of ecosystem services gives the opportunity to some Member States to gain new knowledge on the roles of biodiversity and ecosystems for human well-being. This is particularly relevant for Member States which have already carried out a national ecosystem assessment.

After several rounds of iteration within the working group and following a consultation with several biodiversity research networks a final framework was adopted, which is depicted in Fig. 1. In its simplest version the conceptual framework links socio-economic systems with ecosystems via the flow of ecosystem services, and through the drivers of change that exert pressures on ecosystems including their biodiversity either as consequence of using the services or as indirect impacts due to human activities in general (MA, 2005). Ecosystems are shaped by the interaction of communities of living organisms with the abiotic environment. Biodiversity has several key roles in ecosystems which are essential to support ecosystem functions (e.g., Mace et al., 2012; Cardinale et al., 2012). A specific framework, based on the concept of ecosystem services providers (Luck et al., 2009), was developed for the specific context of MAES (Braat et al., 2015). It essentially links habitats and species protected under the EU Habitats Directive to the spatially explicit supply of ecossytem services by assingning different roles to service providers depending on their contribution in the delivery of ecosystem services. This is particularly relevant for protected habitats which cover nearly half of the EU.

Ecosystem functions are defined as the capacity or the potential to deliver ecosystem services (de Groot et al., 2010). Ecosystem services are, in turn, derived from ecosystem functions and in Fig. 1 they represent the realized flow of services for which there is demand. For the purpose of this framework, ecosystem services also encompass the goods derived from ecosystems.

People benefit from ecosystem (goods and) services. These benefits are, among others, nutrition, access to clean air and water, health, safety, and enjoyment. The benefits derived from ecosystem services cover various dimensions of human well-being, namely basic human needs, economic needs, environmental needs and subjective happiness (Summers et al., 2012). The focus on benefits implies that ecosystem services are open to economic valuation. However, the notion of value should not be restricted to the merely monetary value. Therefore, it was important to include other values as well, such as health value, sociocultural value or conservation value. The non-monetary values of nature may reflect not only the instrumental value of natural capital, but also inherent, fundamental and eudaimonistic values (Jax et al., 2013).

The governance of the coupled socio-economic-ecological system is an integral part of the framework: Institutions, stakeholders and users of ecosystem services affect ecosystems through direct or indirect drivers of change (Kenward et al., 2011). Policies concerning natural resource management (e.g. agriculture) aim to adapt drivers of change to achieve a desired future state of ecosystems. Many other policies (e.g. energy, territorial cohesion) also affect these drivers and thus can be added to the framework as they have an impact on ecosystems even though they might not target them explicitly.

3. Methodology

The application of the conceptual framework for an assessment of ecosystems and their services in an international arena required to define two typologies: a typology for ecosystems that are to be considered in an ecosystem assessment and which are the providers of ecosystem services and a typology of ecosystem services. The aim of these typologies is to allow for the integration and comparison of information from 28 Member States.

3.1. A typology for ecosystems and for ecosystem services

Table 1 contains the major ecosystem types that were selected for the assessment. The basis for the typology of terrestrial and freshwater ecosystems rests on the CORINE Land cover and the

Table 1
Ecosystem types for mapping and assessment under Action 5 of the EU Biodiversity Strategy.

Terrestrial ecosystems	
	Urban
	Cropland
	Grassland
	Woodland and forest
	Heathland and shrub
	Sparsely vegetated land
	Wetlands
Freshwater ecosystems	
	Rivers and lakes
Marine ecosystems	
	Marine inlets and transitional waters
	Coastal
	Shelf
	Open ocean

EUNIS classifications. EUNIS is the European Nature Information System which includes a habitat classification. The typology of marine ecosystems is essentially based on different depth zones and has been recently correlated with the predominant marine habitat types coming from the EU Marine Strategy Framework Directive and the EU-level marine habitat typologies in EUNIS and EUSeaMap (Evans et al. 2014). The use of the ecosystem classification in Table 1 is proposed as basic unit for ecosystem mapping at European scale by enhancing ecosystem types with EUNIS information. The main classes are assumed to allow for consistent assessments from local to national and European scale, i.e. to allow for aggregation of more detailed classifications with a higher spatial resolution. If required, aggregated sub- or trans-national classes such as 'mountainous areas' or 'coastal zones' can be generated using the proposed ecosystem classes as baseline.

As for ecosystem services, the working group decided to adopt the CICES framework (CICES, http://www.cices.eu, Haines-Young and Potschin, 2013). CICES provides a framework for classifying ecosystem services that depend on biodiversity. It is hierarchical in structure, with each level providing a more detailed description of the ecosystem service being considered. The general framework developed by CICES was proposed to be used so that cross-reference can be made between ecosystem services and environmental accounting initiatives like the UN System of Environmental Economic Accounting. This ecosystem service classification is suggested with the aim of providing a flexible and hierarchical tool that can be adapted and refined to the specific situation and needs of states and regions.

3.2. Collection of indicators for mapping and assessment of ecosystem services at continental and national scale

Following the adoption of the analytical framework including a conceptual model and two typologies, a first test of the framework consisted of listing a set of possible indicators which Member States can use to map (or quantify) ecosystem services at the national scale. An ecosystem service indicator is information which communicates the characteristics and trends of ecosystem services, making it possible for policy-makers to understand the condition, trends and rate of change in ecosystem services (Layke et al. 2012). We used a rather broad interpretation of this definition including datasets and proxy indicators such and land cover and land use.

As test cases the working group selected four thematic pilot studies based on the list of ecosystem types in Table 1. A first pilot study considered forests. A second pilot study considered agro-ecosystems including the ecosystem types grassland and cropland. A third pilot study considered freshwater ecosystems, including rivers and lakes. During the start-up phase it was decided to consider also wetlands, classified as a terrestrial ecosystem type, and ground water which is not considered in the ecosystem typology of Table 1. Ground water and wetlands were included because they provide ecosystem services associated with freshwater provision. Arguably, many of the ecosystem service indicators selected for rivers and lakes can potentially be used to measure the status of ecosystem services delivered by wetlands and by ground water. Ground water was assessed assuming the definition of the Water Framework Directive (WFD) in which ground water means all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil. A fourth pilot considered four marine and transitional water ecosystem types. These pilots were chosen because of their potential to inform relevant EU policies which affect the use of natural resources i.e. the Common Agricultural Policy (CAP), the Forest Strategy and the ongoing implementation of the WFD and the Marine Strategy Framework Directive (MSFD). A second important criterion to select the four pilot studies was their potential for using information which Member States already collect in the framework of different environmental reporting obligations on the current EU legislation. This is particularly evident for the reporting required under the Habitats and Birds Directives, the WFD and the MSFD. But also data collections under the CAP, the reporting to EUROSTAT, the European Commission's statistical office, and information based on existing national ecosystem assessments were considered to be relevant sources of information on the status of several ecosystem services. The integration of all those datasets and information will considerably speed up the assessment of EU ecosystems and their services. For the four thematic pilots a rapid appraisal of potential ecosystem service indicators was carried out, building on information that could be gathered during a period of about 6 months (from June 2014 to November 2014)

Volunteers from Member States (from ministries or research institutions), stakeholders, and several EU bodies (European Commission and European Environment Agency) joined the thematic pilots in order to draw on existing initiatives and resources that could be used to measure or monitor ecosystem services at national and European scales. Each pilot was coordinated by at least one Member State and one EU body. Stakeholders included non-governmental organisations with an interest in conservation, research projects funded on the EU's framework program and umbrella organisations with a particular interest in European biodiversity policy such as land owners or hunters.

The four thematic pilots followed a coordinated approach for information gathering, review and compiling. The approach was structured around four main steps. Firstly, the pilot coordinators applied a matrix structure including all CICES ecosystem services as rows and the different ecosystem types considered in each pilot as columns. An EU-wide matrix was populated with indicators based on a literature review (e.g. Egoh et al., 2012; Layke et al., 2012; Crossman et al., 2013) and on an assessment of data and indicators available in various European data centres. This first step of data collection did not try to be exhaustive but to gather basic information to foster the discussion and contribution of interested parties. The matrix then was sent to participating services of the EC and the EEA for eventual addition of further data, and agreement. In a second step, participant Member States and stakeholder groups were requested to populate a country-level matrix with ecosystem service indicators available in their country. In a third step, the information on all collected indicators per ecosystem type and per ecosystem service was synthesized according to reporting body, data availability, units of measurement and compiling agency.

The availability of the data was scored from 1 to 6 according to the following criteria: (1) national/European data with complete coverage are readily and publicly available; (2) national data are available with restricted use; (3) data can be abstracted from a model and require expert knowledge; (4) data are available at sub national scale or do not consistently cover the territory; (5) no data is available for this indicator or models are in development; and (6) unknown data status. The resulting summary charts with classified indicators were discussed in a two day technical workshop. The fourth and final step of synthesis yielded a summary table which includes per ecosystem and per service one or more proxies which are assumed to be suitable for the development of spatial ecosystem service indicators for Action 5 of the EU Biodiversity Strategy. Each of the final indicators suggested were evaluated according to two criteria: data availability (as defined above), and ability to convey information to the policy making and implementation processes (Layke et al. 2012). Thus, a final quality label was assigned to each indicator depending on their combined score for each of these two criteria (Table 2).

4. Results

4.1. Available indicators for mapping and assessment of ecosystem services

After a first round of consultation with all contributing actors a total of 1118 potential ecosystem service indicators was collected across all ecosystem services types and all ecosystem types considered in this study. This total also included double counts as often similar indicators were used for different ecosystem types or the same indicators were reported by different contributions. Next these indicators were charted, scored according to their data availability and reviewed in the expert workshop. After the review process and excluding doubles, 327 ecosystem services indicators were retained and given a quality label. Of this selection of 327, 64 indicators received the highest quality or green label, 124 received the yellow label, 103 were labelled red, and 36 had a grey label for which the expert panel did not assign a quality label (Fig. 2).

To some extent Fig. 2 reflects the state of knowledge on ecosystem services that can be used for policy implementation at EU level. For forest services, 115 indicators were finally selected, showing the significant amount of information that is available for forests but also demonstrating the importance of forests in delivering many services. The agro-ecosystems pilots retained 69 indicators in the final selection. The freshwater pilot retained 109 indicators but contrasting with forests many indicators are shared among 4 ecosystem types and are thus not unique as in the forest pilot study. The marine pilot delivered 33 indicators for four ecosystem types, demonstrating that data to measure the state of marine ecosystem services is less available than for terrestrial and freshwater systems.

One fifth of the indicators for ecosystem services received the highest quality label (green colour code, Table 2), corresponding to indicators that are widely available and supposedly ready to use for reporting under Action 5 of the EU Biodiversity Strategy. Importantly, many indicators characterized with a yellow or red quality label are available for usage but require additional expertise or interpretation before they can be used for mapping and assessment of ecosystem services.

4.2. Ecosystem service indicators per thematic pilot study

The final set of 327 ecosystem service indicators is available in the supplement of this paper, assorted per thematic pilot study (Tables S2–S5). Here we summarize the most important observations.

4.2.1. Forest ecosystem services

Indicators for provisioning ecosystem services delivered by forests were primarily drawn from national forest inventories and European forest data centres and relate to the production of timber (Table S2). Indicators related to wild food supply by forests are under development while indicators for water provision are scarce or require modelling approaches that are able to assess the specific contribution of forests to water supply. Regulating ecosystem services delivered by forest were poorly covered by available indicators and many of these were given a red quality label (Table S2). Often area based indicators such as the relative surface area of forests are used to assess regulating forest ecosystem services. Importantly, forests have a crucial role in global climate regulation and indicators for this service are coded in green reflecting the good availability of data at European and at country level. High quality indicators for cultural forest ecosystem services are not available (Table S2) which means that more work is needed to assess how forests contribute to this group of ecosystem services. Visitor statistics are frequently used as indicator but such data is often not readily available.

Table 2
Quality label of ecosystem service indicators based on data availability and the ability to convey information to the policy making and implementation processes.

High quality label (green) ●	Available indicator to measure the quantity of an ecosystem service at a given CICES level for which harmonised, spatially-explicit data at European scale is available and which is easily understood by policy makers or non-technical audiences. Spatially-explicit data in this context refer to data that are at least available at the regional NUTS2 level or at a finer spatial resolution. CICES classifies ecosystem services at 4 hierarchical levels. Sometimes, it is more cost-effective to consider an assessment of ecosystem services at a higher CICES level than at class level, especially if aggregated indicators are available. Indicators that aggregate information at higher hierarchical CICES level can therefore also have a green label.
Medium quality label (yellow) ●	Available indicator to measure the quantity of an ecosystem service at a given CICES level but for which either harmonised, spatially-explicit data at European scale is unavailable or which is used more than once in an ecosystem assessment, which possibly results in different interpretations by the user. This is typically the case for indicators that are used to measure ecosystem condition, which are reused to assess particular ecosystem services. This label also includes indicators that capture partially the ecosystem service assessed.
Low quality label (red) ●	Available indicator to measure the condition of an ecosystem, or the quantity of an ecosystem service at a given CICES level but for which no harmonised, spatially-explicit data at European scale is available and which only provides information at aggregated level and requires additional clarification to non-technical audiences. This category includes indicators with limited usability for an ecosystem assessment due to either high data uncertainty or a limited conceptual understanding of how ecosystems deliver certain services or how ecosystem condition can be measured. The ability to convey information to end-users is limited and further refined and/or local level assessments should be used for verifying the information provided by this type of indicators.
Unknown quality label (grey) ●	Unknown availability of reliable data and/or unknown ability to convey information to the policy making and implementation processes

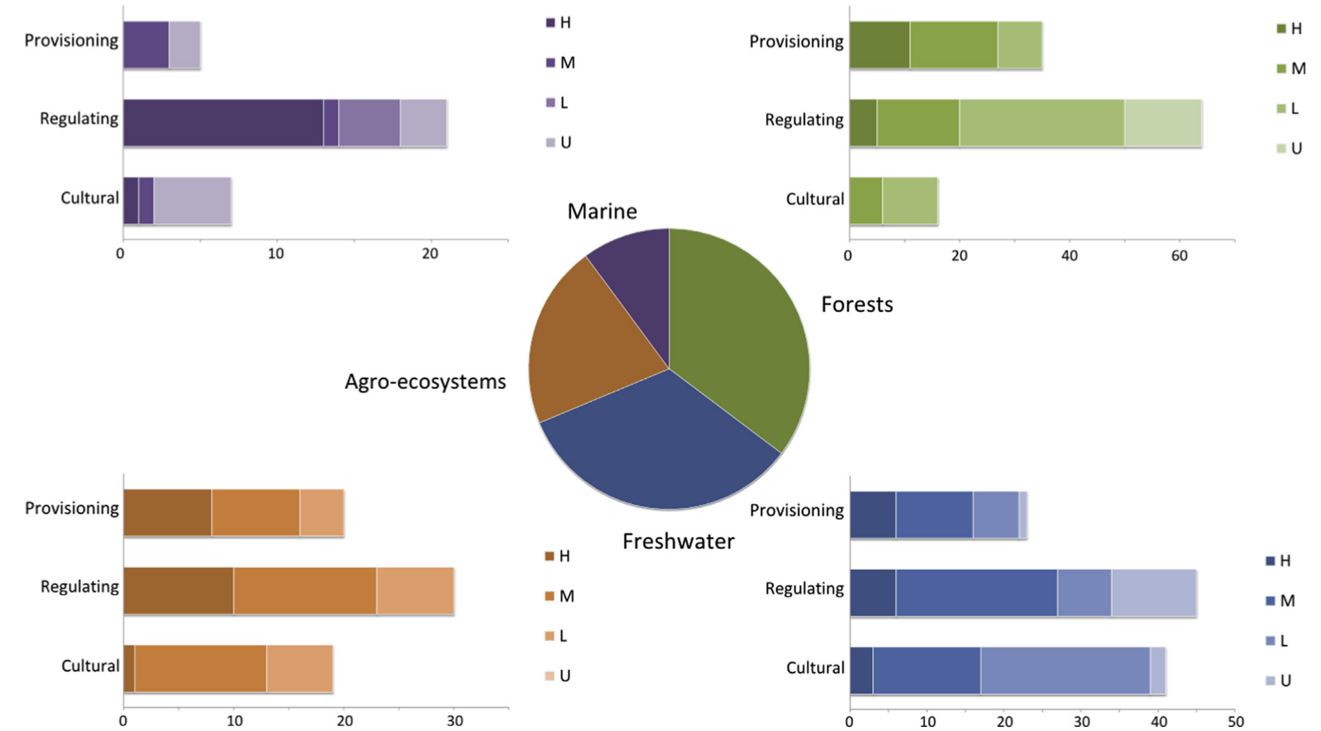

Fig. 2. Number and classification of the indicators proposed to map ecosystem service in EU. The letters refer to the quality label of indicators, as follows: H for high, M for medium, L for low and U for unknown (see also Table 2 for a detailed description of the quality labels) The data used to make this figure is included on Table S1 of the supplement.

4.2.2. Agricultural ecosystem services

The primary role of agriculture is to provide food, feed, fibre, and energy. Therefore, associating agricultural production to provisioning services is straightforward, and many indicators are available at EU scale (Table S3). Data relevant to this set of services are largely provided by CAP monitoring and span from parcel based data, which are often of restricted access, to regional statistics which are publicly available. Indicators for regulating services delivered by agro-ecosystems are mainly available for soil related services such as erosion control and nitrogen fixation (Table S3). Following increasing attention for the role of pollinators in sustaining agricultural production also indicators for pollination are becoming available for usage in assessments. In Europe, farmlands are shaped by their thousand-year old history of human management and hence, cultural ecosystem services are deeply rooted in agro-ecosystems. Still, only a few indicators for cultural ecosystem services are readily available in monitoring frameworks (Table S3) and just as for forests more efforts are needed to provide high quality data for measuring cultural values (e.g. tourism in agricultural areas, sense of place).

4.2.3. Freshwater ecosystem services

This pilot assessed the availability of indicators delivered by rivers and lakes. It covered also wetlands and ground water. Evidently, data on freshwater abstraction as well as production statistics of freshwater fisheries are regarded as the best available information for provisioning ecosystem services even if they are not always public or only with very low resolution (Table S4). Indicators for regulating ecosystem services depend frequently on water quality monitoring reporting (or modelling approaches) and thus rest on the assumption that a high water quality is positively related to the delivery of ecosystem services. Cultural ecosystem services are poorly covered by indicators, despite the enormous contribution of water bodies as sources of recreation.

Indicators for provisioning and regulating and maintenance services listed under ground water have mostly an abiotic character: the location of groundwater bodies, abstracted volumes; the groundwater level, volumes of CO_2 injection (Table S4). We refer to the discussion for further reflections on the inclusion of ground water in this study.

4.2.4. Marine ecosystem services

Indicators for provisioning marine ecosystem services depend strongly on fishery statistics but none of the indicators were assigned with the highest quality label due to a poor spatial coverage of catch statistics or poor data accessibility (Table S5). Similar to regulating freshwater ecosystem services, indicators for regulating marine ecosystem services are based on sea water quality observations or modelling and thus imply a correlation between ecosystem condition and the delivery of ecosystem services. In correspondence with the observations for all other thematic pilots, high quality data to assess cultural ecosystem services supplied by marine ecosystems were not available and the data status of the present indicators listed in Table S5 was in general not known.

4.3. Selection of indicators for a first assessment of ecosystem services at EU and national scale

Table 3 provides a selection of high quality labelled (green) and medium quality labelled (yellow) indicators based on the summary tables of the four pilot studies which covered together nine ecosystem types. Where relevant, it assigns to each ecosystem service the main contributing ecosystem i.e. the ecosystem, which is the major provider of a particular ecosystem service. For example, forests are considered principal providers of wild food products, biomass for materials and energy, or climate regulation. Equally, agro-ecosystems are considered principle providers of food and biomass and several regulating services that are connected to food production. Freshwater systems are considered principle providers of water provisioning services. Marine

Table 3
Best available indicators for assessment of ecosystem services across different ecosystems. All ecosystem services are presented at the class level of CICES except ecosystem services in italic which are at CICES group level. The CICES division level is indicated by brackets in cases where classes have similar names (i.e. division > group > class). The colour codes refer to the quality labels defined in Table 2. For blank cells, no indicators were retained.

Ecosystem services	Main terrestrial and freshwater ecosystem	Indicator for terrestrial and freshwater ecosystems	Indicator for marine ecosystems
Cultivated crops	Cropland	● Area and yields of food and feed crops	● Yield
Reared animals and their outputs	Cropland Grassland	● Livestock	● Landings ● Catch per unit effort (where applicable)
Wild plants, algae and their outputs	Forest	● Distribution of wild berries (modelling)	
Wild animals and their outputs	Forest	● Population sizes of species of interest	
Plants and algae from in-situ aquaculture			
Animals from in-situ aquaculture	Lakes and rivers	● Freshwater aquaculture production	
Water (Nutrition)	Lakes and rivers	● Water abstracted	
Biomass (Materials)	Cropland Forest	● Area and yield of fibre crops ● Timber production and consumption statistics	
Water (Materials)	Lakes and rivers Forest	● Water abstracted ● Total supply of water per forest area (modelling)	
Plant-based resources	Forest	● Fuel wood statistics	
Animal-based resources			
Animal-based energy			
(Mediation of waste, toxics and other nuisances)	Forest	● Area occupied by riparian forests ● Nitrogen and Sulphur removal (forests)	● Nutrient load to coast ● Heavy metals and persistent organic pollutants deposition ● Oxyrisk
Mass stabilisation and control of erosion rates	Forest Cropland Grassland	● Soil erosion risk or erosion protection	● Coastal protection capacity
Buffering and attenuation of mass flows			
Hydrological cycle and water flow maintenance			
Flood protection	Wetlands	● Floodplains areas (and record of annual floods) ● Area of wetlands located in flood risk zones	● Coastal protection capacity
Storm protection			
Ventilation and transpiration	Cropland Grassland	● Amount of biomass	
Pollination and seed dispersal	Cropland Grassland	● Pollination potential	
Maintaining nursery populations and habitats		● Share of High Nature Value farmland ● Ecological Status of water bodies	● Oxygen concentration ● Turbidity ● Species distribution ● Extent of marine protected areas
Pest and disease control			
Weathering processes	Cropland Grassland	● Share of organic farming ● Soil organic matter content ● pH of topsoil ● Cation exchange capacity	
Decomposition and fixing processes	Cropland	● Area of nitrogen fixing crops	
Chemical condition of freshwaters	Lakes Rivers Wetlands	● Chemical status	
Chemical condition of salt waters	Marine systems		● Nutrient load to coast ● HM and POP loading ● Oxyrisk
Global climate regulation by reduction of greenhouse gas concentrations	Forest	● Carbon storage and sequestration by forests	● Carbon stock ● Carbon sequestration ● pH; ● Blue carbon ● Primary production
Micro and regional climate regulation	Forest	● Forest area	
Physical and experiential interactions	Forest Cropland	● Visitor statistics	
Intellectual and representative interactions	Grassland Lakes		
Spiritual and/or emblematic			
Other cultural outputs		● Extent of protected areas	

ecosystems were considered separately in Table 3 because the classification of the services they provide (following CICES) cannot be aligned with terrestrial and freshwater systems. Taken together the indicators in Table 3 provide the best currently available information to assess ecosystem services at the national and EU scale. However, for at least six ecosystem services no suitable indicator with the highest quality score could be found.

Probably due to the poor data availability of spatially-explicit socio-economic datasets, the results of Table 3 are biased towards ecosystem services supply. The economic valuation and more detailed analysis of beneficiaries are foreseen in a second phase of Action 5. The challenge thus remains, to find suitable indicators to address all the components of the MAES conceptual framework (Fig. 1) so as to respond to the key policy questions (Supplement 2).

5. Discussion

The steps followed so far to implement Action 5 of the EU Biodiversity Strategy allowed (a) to establish the structure, analytical framework and the first methodological approach (set of indicators) of a non-binding policy; (b) to gather knowledge and experience from very different actors through the activities of the MAES working group; (c) to integrate opinions and raise awareness across the 28 Member States of the EU but also beyond. The number of contributions and the high attendance rates of Member States to the MAES working group meetings as well as the good reception of the MAES high level workshop (a workshop held on 22 May 2014 at ministerial level) confirm the increasing relevance and interest of this process in Europe. Still we can reflect here on the a number of weaknesses of the assessment approach presented in this paper, keeping in mind that this is part of a broader, complex policy process.

5.1. Methodological challenges

The indicator framework proposed in this study as well as the testing phase using ecosystem based pilots is based on collaboration among researchers, civil servants at EU and national levels, and other stakeholders. Such a joint exercise warrants that the scientific knowledge based on ecosystems is made applicable and useful to support policy and decision making and implementation (e.g. for monitoring progress to biodiversity targets) while also taking into consideration the issue of feasibility. But it also leads to a number of additional challenges which need some critical reflection.

A first drawback is that the indicators proposed in this study do not always quantify the potential or actual contributions of ecosystems for regulation and maintenance, but may measure a pressure on ecosystems (e.g. share of agroforestry within floodplains), an ecosystem state (e.g. ecological status of water bodies) or an impact on ecosystems (e.g. sediments removed from dams, presence of alien species). Such indicators are thus used as surrogates of ecosystem services. This is common practise (Egoh et al. 2012, Layke et al. 2012) and, to our view, acceptable insofar the conceptual framework used in this study involves the assumption that good environmental conditions indicate a healthier and more resilient ecosystem that provides more services and maintains the capacity to provide them for the future (Chapin et al., 2000; Balvanera et al. 2006; Schindler et al. 2010). However, the relationship between ecosystem condition and services has not been explicitly explored in this process and needs further scientific attention (Palmer and Febria, 2012).

A second shortcoming is that data availability is not the best criterion for identifying ecosystem services indicators as it may direct the search of indicators towards existing national or EU wide monitoring programmes. This is not always resulting in optimal indicators (Geijzendorffer and Roche 2013) but it increases the ownership of a joint approach to ecosystem assessment in Europe. We conclude that the set of indicators presented in this paper rewards applicability with respect to quantity (number of indicators).

The third and fourth steps of the methodology pursued the synthesis and classification of the available indicators. However, despite of the adoption of two typologies and a common assessment framework for selecting ecosystem service indicators, we could not exclude different interpretations of data quality among the different pilot studies. Each thematic pilot inevitably involved a separate disciplinary approach to ecosystem assessment which could not be entirely streamlined during the course of this study. Hence the synthesis and labelling of indicators could benefit from further homogenisation. This lesson can be useful for upcoming processes like the IPBES regional assessments or the ongoing development of ecosystem accounts which is foreseen in the EU Biodiversity Strategy; it could need a set of rigid guidelines and procedures to ensure consistent reporting across ecosystem types (e.g. Mononen et al., 2015, Edens and Hein, 2013).

5.2. Gaps

Several knowledge gaps became apparent during our study. The first one is the development and subsequent monitoring of indicators for cultural ecosystem services (Daniel et al., 2012; Paracchini et al., 2014). All thematic pilot studies reported mainly low and medium quality labelled indicators. Visitor statistics returned as single most important indicator to assess the role of different ecosystem types as sources for several classes of cultural ecosystem services. A consistent monitoring of the number and origin of people who visit national parks across the EU would be a first but important step to fill this gap. It also would provide strong arguments for conservation (Balmford et al., 2015).

A second gap relates to the link between some dimensions of biodiversity, such as species diversity, and the delivery of ecosystem services, which requires further research and evidence gathering (Harrison et al., 2014). Whereas to some extent, there remains scientific uncertainty about the exact relationships between biodiversity, ecosystem functioning and ecosystem services, a better availability and usability of biodiversity datasets will provide new insights and will boost the mapping and assessment of ecosystem services, in particular of cultural services that are strongly connected to biodiversity (bird watching, mapping of emblematic species).

A third weakness observed is the low number of indicators proposed for the analysis of the demand and the valuation of ecosystem services. There are also controversial issues ignored such as how stakeholders' values influence the assessment of ecosystem services. Some of these aspects will be addressed in the forthcoming ecosystem accounting exercise of the Biodiversity Strategy.

There remain also several conceptual difficulties with ecosystem services delivered by agriculture which warrant some further reflection. This is mainly because the proposed indicators do not discriminate between the share of the contribution to provisioning services supplied by agro-ecosystems and the role of human energy inputs in contributing to total yield (Björklund et al., 1999). Yet these inputs are explicitly addressed in the conceptual framework (“Ecosystems use and management” and “Other capital inputs” in Fig. 1) but still not captured by the indicators proposed.

5.3. The use of CICES as classification system for ecosystem services

This paper introduced a typology of ecosystems and used CICES as basis to classify ecosystem services. These two typologies defined a matrix which was the basis for collecting indicators. Put differently, indicators were assumed to cover a specific ecosystem and indicate the quantity of a specific ecosystem service. For forests, cropland and grassland this approach worked well albeit different data providers use frequently different definitions to spatially delineate these ecosystems than does the European CORINE Land Cover classification, which forms the basis of our typology. For wetlands, ground water, rivers and lakes and marine ecosystems the matrix approach to collect ecosystem service indicators presented more challenges. Often, ongoing data reporting for these ecosystem types is done at a higher level of aggregation so that the spatial coverage of the original data remains unclear and the delimitation of habitats where specific ecosystem functions (or ecological processes) occur becomes unclear (e.g. nitrogen retention or flood protection by riparian zones).

This study tested for the first time the applicability of the CICES classification to set up an indicator framework for the assessment of ecosystem services at national and international level. The hierarchical structure of CICES was reported as useful to bundle services at class level in cases for which indicators were only available at higher hierarchical level. Indicators for marine ecosystem services were indeed mostly available at CICES group level (the 3rd of four levels) whereas other pilots reported mostly at class level (the 4th and most detailed level). The hierarchical structure of CICES allowed better reuse of indicators that are developed under other frameworks or reporting streams. This is useful for operationalization of ecosystem services which refers to their integration into land, water and urban management and decision-making.

Applying the CICES classification for marine or freshwater ecosystems is less evident. Many classes are not relevant as marine and freshwater ecosystems do not provide those services that are strongly linked to terrestrial ecosystems. Furthermore, some classes lead to difficulties in proper interpretation. For freshwater ecosystems conceptual difficulties can be encountered when assessing regulation/maintenance services because of the nature of the water cycle, which underpins almost all regulation services. For example, the service class 'hydrological cycle and water flow maintenance' is difficult to individualise from other services and to link to living processes (the red coloured text in Table S4 reflects these difficulties). Another example for both ecosystem types is the lack of knowledge/data for distinguishing between the role of biota and the role of ecosystems in the CICES division 'mediation of waste'. In general, interpretations of the CICES classes differ if terrestrial, freshwater or marine systems are considered. Importantly, at several entry points in CICES, users referred to other ecosystems as providers of the service. This shows the importance of developing an integrated approach across connected ecosystems such as floodplains.

Ground water represents a special case as it challenges both typologies used in this study. In the pilot on freshwater ecosystem services, ground water (as ecosystem) was considered to deliver ground water for drinking and non-drinking purposes, several regulating and maintenance services including climate regulation and mediation of waste, as well as cultural services nearby hot water springs or caves. The pilot on agro-ecosystems included indicators for two CICES classes related to ground water (ground water for drinking and non-drinking purposes) and assigned them to cropland or grassland. Interestingly, apart from the visitor statistics, only physical or abiotic indicators were retained to assess ecosystem services delivered by ground water, reflecting also perhaps the limited knowledge on the biotic groundwater communities. The pilots therefore resulted in two possible approaches for the inclusion of ground water in ecosystem service assessments.

The easiest and most pragmatic approach is to assign the groundwater ecosystem services to the ecosystem types of Table 1 lying above the ground. But there is also an ecological rationale for doing so. The generation of groundwater ecosystem services is mediated by ecological processes which take place in forests or agricultural ecosystems where vegetation influences the re-charge of groundwater layers beneath them. In addition, part of the ground water is in the root zone of these ecosystems whereas other, deeper, groundwater layers are part of the abiotic crust of the earth. These aquifers often also receive ground water from above but are mainly abiotic depositories of ground water generated elsewhere (in spite of the presence of some biotic organisms).

A second approach, considers ground water as a separate ecosystem and accounts for the specific services delivered by ground water (Griebler and Avramov 2014). Groundwater abstraction for different user purposes is assigned to this ecosystem type and not to the above ground ecosystem where the abstraction takes place. A major drawback is how to conclude on a spatial delineation which does not overlap with the present typology.

None of the thematic pilots considered ground water as a subsoil asset or as system which delivers abiotic flows (see Fig. 4 of Maes et al. 2013). It is difficult indeed to always identify a clear boundary between the abiotic and ecosystem components of natural capital. Water is a key example in this regard which also comes through in the treatment of ground water in the different pilots. A guiding question for classifying natural capital components into abiotic or ecosystem elements needs to address whether or not a given component is primarily shaped or maintained by biological organisms and their interaction with the abiotic environment. A review, update or even extension of the CICES classification, based on the most recent scientific evidence and methodological guidance on ecosystem accounting, is thus needed; not only to accommodate ground water services but also to carefully examine the contribution of biota and ecosystems to different types of ecosystem services already identified.

6. Conclusion

This paper demonstrates that there is potential to develop a first ecosystem assessment on the basis of existing data if they are combined in a creative way. However, substantial data gaps remain to be filled before a fully integrated and complete ecosystem assessment can be carried out. We presented an extensive list of potential indicators, which can be used, together with a typology, to perform a first mapping of ecosystem condition and ecosystem services. Several EU policies including agriculture, water, marine, forest and nature policies, already compile data and indicators for ecosystem assessments, even if they were originally not designed to do so. Usage of these sector-specific data would thus facilitate the mainstreaming of biodiversity and ecosystem services, which is embedded in EU 2020 Biodiversity Strategy.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ecoser.2015.10.023.

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