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Mapping and Assessment of Ecosystems and their Services

An analytical framework for mapping and assessment of ecosystem condition in EU

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Environment

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Summary

The fifth MAES report presents indicators for mapping and assessment of ecosystem condition at European level. A set with specific indicators is available for assessment of ecosystem condition per ecosystem type. A core set with key indicators is available to support an integrated ecosystem assessment across ecosystem type.

Supporting documents are available at https://circabc.europa.eu/w/browse/f7a929ac-bb72-4d25-99f1-abaa1f3a1f34

Information about MAES is available at https://biodiversity.europa.eu/maes

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EXECUTIVE SUMMARY

Action 5 of the EU Biodiversity Strategy to 2020 foresees that Member States will, with the assistance of the Commission, map and assess the state of ecosystems and their services in their national territory by 2014. This report provides operational guidance to the EU and the Member States on how to assess the condition (or the state) of Europe's ecosystems.

Ecosystem condition is the physical, chemical and biological condition or quality of an ecosystem at a particular point in time. The concept of ecosystem condition is strongly linked to well-being through ecosystem services. Ecosystems need to be in good condition to provide multiple ecosystem services, which, in turn, deliver benefits and increase well-being. Drivers of change can have a positive (e.g. conservation) or negative (pressures) impact on ecosystem condition.

Ecosystem condition can be measured using indicators. The indicators proposed in this report are based on the work delivered by the MAES ecosystem pilots. Each ecosystem pilot consists of a group of experts with particular knowledge in a certain area: forests, agro-ecosystems, urban ecosystems, freshwater ecosystems, marine ecosystems, nature, and soil. The choice for these particular pilot studies was based on sectoral policy needs but also considered the specific organization of knowledge inside different European institutions and services. The thematic pilots followed a common roadmap to prepare this report and they have used a common concept across ecosystems. The indicators can be used to measure progress to target of the EU's nature and environmental legislation; they are spatially-explicit, and the underpinning data can be organised in a natural capital accounting framework. Input from the Member States, other scientific experts and environmental policy units of the European Commission was possible during a special workshop and two meetings. These meetings ensured that the final selection of indicators is policy relevant with the capacity to inform a broad array of policies related to the use or the protection of natural resources.

For every MAES ecosystem type indicators for pressure and indicators for ecosystem condition are available. Separate tables are included for urban ecosystems, forests and woodland, wetlands, and rivers and lakes. Combined tables are included for cropland and grassland, and for heathland and shrub and sparsely vegetated land. Also marine ecosystems are covered with indicator tables for marine inlets and transitional waters and coastal ecosystems, and for shelf and open ocean. Every indicator table uses the same classification. Pressures are organised according to their major impact class: habitat conversion, climate change, over-exploitation (or over-harvesting), pollution and nutrient enrichment, introductions of invasive alien species, and other pressures. The ecosystem condition indicator tables recognised the difference between environmental quality (abiotic quality) and ecosystem attributes (biotic quality). Special attention goes to indicators based on species diversity, soil characteristics and indicators, which are monitored under the Birds and Habitats Directives.

This report also includes for every ecosystem type a synthesis of the expected links between pressure, ecosystem condition and ecosystem services and couples this information to a policy narrative. These examples illustrate how the indicator set can be used to address various policy questions.

The added value of this indicator framework is that for the first time a comprehensive and consistent list of indicators for ecosystem condition is collected across terrestrial, freshwater and marine ecosystems. The indicators can be used to map and assess ecosystem condition per ecosystem type but the framework also allows horizontal or thematic assessments across different ecosystems (for instance on soil).

Importantly, the MAES indicator framework integrates different other indicator frameworks, such as the SEBI (Streamlining European Biodiversity Indicators), the Agri-Environment Indicators, as well as indicators derived from the Habitats, Birds, Water Framework and Marine Strategy Framework Directives. The MAES ecosystem condition indicators can also provide essential information to measure progress towards the Sustainable Development Goals.

Not all the indicators, which are presented in this report, have equal policy uses and equal data coverage. Some indicators are already reported under or used by other policy frameworks. The indicators with at least two other policy uses and for which a baseline and time series of data is available at European scale are considered key indicators to measure pressure and ecosystem condition. Taken together across the different ecosystem types, these indicators form a core set which, in combination with information about ecosystem extent and ecosystem services, serves as an essential input for an integrated ecosystem assessment.

Supporting documents can be found at https://circabc.europa.eu/w/browse/f7a929ac-bb72-4d25-99f1-abaa1f3a1f34

Mapping and Assessment of Ecosystems and their Services

AN ANALYTICAL FRAMEWORK FOR MAPPING AND ASSESSMENT OF ECOSYSTEM CONDITION

1 INTRODUCTION

1.1 Context

The European Union's (EU) Biodiversity Strategy to 2020[1] aims under its Target 2 to maintain and enhance ecosystem services in Europe. To this end, the European Commission is developing a knowledge base on ecosystems including aspects of ecosystem condition, the capacity of ecosystems to provide services, biodiversity and the pressures they are exposed to. Action 5 of the Strategy sets the basis for this knowledge base. It requires 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 EU's seventh Environment Action Programme to 2020[2] reinforces the targets and actions of the biodiversity strategy. Its first objective is to protect, conserve and enhance the Union's natural capital. Natural capital refers to the biodiversity that provides goods and services we rely on, from fertile soil and productive land and seas to fresh water and clean air. It includes vital services such as pollination of plants, natural protection against flooding, and the regulation of our climate.

The Working Group on Mapping and Assessment of 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 across Member States and at European level (Maes et al., 2013). Substantial part of the work of MAES is organised in so-called thematic pilots focussing on nature, agriculture, forests, freshwater, marine, urban and soil. The report adopted in April 2013 proposed a conceptual framework linking biodiversity, ecosystem condition and ecosystem services to human well-being. Furthermore, it developed a typology for ecosystems in Europe and promotes the CICES classification for ecosystem services. In a next step, this framework was further developed by providing guidance and indicators. Practical guidance has been provided through a common assessment framework while a selection of indicators has been proposed to map and assess ecosystem condition and ecosystem services (Maes et al., 2014). Two more reports from the Working Group are available. The third MAES report synthesizes the European Environment Agency's (EEA's) work on ecosystem mapping and provides short assessments of pressures, condition and biodiversity for main ecosystem types mainly based on datasets derived from reporting under EU environmental policies (Erhard et al., 2016). The

[1] EU Biodiversity Strategy to 2020: http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm
[2] 7th EAP: http://ec.europa.eu/environment/action-programme/

fourth MAES report addresses urban ecosystems (Maes et al., 2016). All reports are available on Europa[3] and BISE[4].

This report further consolidates and enhances the operational guidance on mapping and assessment of ecosystem condition. There is a need to further develop and update the list of indicators for ecosystem condition proposed in the 2nd MAES report (Maes et al., 2014) according to a joint framework across different ecosystem types which can provide the basis for an integrated ecosystem assessment to evaluate the achievements of the EU Biodiversity Strategy.

1.2 The importance of mapping and assessment of ecosystem condition

Are Europe's ecosystems healthy so that they can continue providing ecosystem services in a sustainable way? This is one of the key questions which Action 5 ultimately has to answer.

Addressing this question means that we establish a common definition of ecosystem condition and that we select a suitable set of indicators per ecosystem type. It also requires a further understanding of the relationship between the ecosystem condition and the delivery of ecosystem services, in order to assess whether ecosystems services are maintained and enhanced, an important target of the biodiversity strategy. In particular, mapping and assessing ecosystem condition can help prioritize where green infrastructure could be best deployed and degraded ecosystems need to be restored. Restoring 15% of degraded ecosystems in not only a European target but also a global target which needs to enhance ecosystem resilience and contribute to climate change mitigation[5].

Ecosystems are multi-functional which means that they provide multiple ecosystem services. Forest, wetlands and other natural ecosystems typically provide bundles of different ecosystem services (for instance storing carbon while regulating water flows and improving water quality). But trade-offs occur as well when a management aimed at increasing or even maximising one or more services results in the decrease of other services. Maximising crop yields for example can lead to a decrease in soil protection, water purification and biodiversity. One important question is how synergies and trade-offs among ecosystem services are related to ecosystem condition. Or put it another way, does increasing the condition of ecosystems result in more synergies in the delivery of ecosystem services?

Detailed knowledge about the pressures (or in a broader sense the drivers of change) that continue to impact ecosystems is of paramount importance as well, in particular to support policies which aim to reduce pressures and thus, in turn, contribute to a better condition of ecosystems.

Healthy ecosystems are the fundamental basis for a resilient society and a sustainable economy. Healthy soils underpin forestry and agricultural production and income of landowners. Besides direct economic benefits healthy

[3] http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm
[4] MAES website on BISE: http://biodiversity.europa.eu/maes
[5] Aichi target 15: By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

forests are essential providers of many regulating ecosystem services. Healthy rivers and lakes provide abundant clean water, are habitats for fish and wildlife and provide recreation opportunities. Clearly, an indicator framework for ecosystem condition goes beyond biodiversity policy and needs to be able to inform other policies with high socio-economic relevance as well. It is a key component for integrating ecosystem services into decision-making[6] and for impact assessment.

1.3 Key challenges for an EU analytical framework on ecosystem condition

The key challenge of this report it to provide operational guidance to the EU and the Member States on how to assess the condition of Europe's ecosystems taking into account the specific policy context. There is indeed a number of issues which have to be considered in MAES which makes the assessment of condition different than previous studies which developed concepts and indicators to assess ecological integrity.

An agreed set of indicators, developed according to a common concept across ecosystems, with the capacity to inform a broad array of policies related to the use or the protection of natural resources needs to be:

- aligned with the MAES conceptual framework which links socio-economic systems with ecosystems via the flow of ecosystem services, and through the drivers of change that affect ecosystems either as consequence of using the services or as indirect impacts due to human activities in general;
- supportive to the objectives of the EU's environmental legislation (notably the nature, water and marine directives);
- policy relevant: indicators and assessments need to primarily support EU environment policy as well as related national policies and also other policies which have an impact on ecosystems;
- supportive to the objectives of developing natural capital accounts: the indicators need to be quantifiable, there should be regular updates of the datasets underpinning the indicators; indicators need to be assigned to the proper accounting tables;
- spatially explicit: consider current spatial distribution of ecosystems and their use (often derived from land cover and land use information) and be specific for each ecosystem type (this requirement sets a spatial reference);
- contributing to measuring progress/trends against a policy baseline towards different biodiversity policy targets (this requirement sets a baseline or reference point in time).

1.4 Structure of the report

The report is structured as follows. Chapter 2 defines ecosystem condition and puts it in the perspective of the MAES conceptual framework which has been developed in the 1st MAES report (Maes et al., 2013). Chapter 2 also provides the EU context and lists the requirements for the indicator framework. Chapter 3 describes the thematic approaches and the procedures which have been followed by the pilots to select a final list of indicators. Chapter

[6] Cf. Action 1 of the EU Action Plan for nature, people and the economy
http://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/communication_en.pdf

4 is the core of this report. It contains indicator tables per main ecosystem type. These indicators describe how to map and assess the main pressures on ecosystems and how to map and assess ecosystem condition. Chapter 5 provides an integrated view and paves the way for an EU wide ecosystem assessment. Chapter 6 presents the major conclusions and outlook.

2 A COMMON CONCEPT FOR ECOSYSTEM CONDITION

2.1 Definitions

Ecosystem condition refers to the physical, chemical and biological condition or quality of an ecosystem at a particular point in time. Pressure refers to a human induced process that alters the condition of ecosystems.

Here we also refer to two other definitions of ecosystem services which are commonly used. The Millennium Ecosystem Assessment has defined ecosystem condition as the capacity of an ecosystem to deliver ecosystem services, relative to its potential capacity (MA, 2005). This distance to target approach is also implemented in the status information of EU environmental directives.

The accounting community has proposed the following definition in the SEEA-EEA technical recommendations (see also section 2.3.4): Ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics. All these definitions are important when proposing a set of indicators which measure ecosystem condition.

For the purpose of MAES, ecosystem condition is usually used as a synonym for 'ecosystem state'. It embraces legal concepts (e.g. conservation status under the Birds and Habitats Directives, ecological status under the Water Framework Directive and environmental status under the Marine Strategy Framework Directive) as well as other proxy descriptors related to state, pressures and biodiversity. Ecosystem condition is used to assess trends and set targets related to the improvement of environment health.

2.2 Conceptual model

Figure 2.1 contains a simplified MAES conceptual model and is based on Grizzetti et al. (2016). The full conceptual model is presented in the first MAES report (Maes et al., 2013) and highlights the underpinning role of biodiversity. This simplified version has been used to guide the indicator selection per ecosystem type (see also chapter 3).

The concept of ecosystem condition is linked to well-being through ecosystem services. Ecosystems need to be in good condition to provide a set of essential services which, in turn, deliver benefits and increase well-being. Drivers of change can have a positive (e.g. conservation) or negative (pressures) impact on ecosystem condition.

Ecosystem condition can be measured using indicators. There are links between pressures, condition and ecosystem services (European Environment Agency, 2015a). For instance, ecosystems are more likely to be in a good condition if the pressures on ecosystems are absent. Likewise, ecosystems with a high capacity to store carbon, water and nutrients are probably in good condition. The links between pressure and ecosystem condition on the one hand and between condition, biodiversity and ecosystem services on the other hand are an important part of the framework. When assessing ecosystem condition and ecosystem services it is essential to reflect on these links and to describe them using scientific evidence. These relationships are often not linear. Ecosystem condition can remain very poor due to historical contamination or nutrient enrichment, also when emissions of pollutants or nutrients have been ended.

The relation between ecosystem condition and regulating ecosystem services is usually positive (Smith et al., 2017). However, for provisioning or cultural ecosystem services such as recreation in nature reserves a non-linear relationship is often observed. A moderate use of ecosystem services is positively related to ecosystem condition but intensive use of provisioning ecosystem services has mostly a negative impact on ecosystem condition and results in ecosystem degradation. Provisioning services such as fish and timber, if overused, can effectively act as a pressure on ecosystems. To avoid over-exploitation of provisioning services, safe thresholds need to be set and well-designed indicators could reflect these limits.

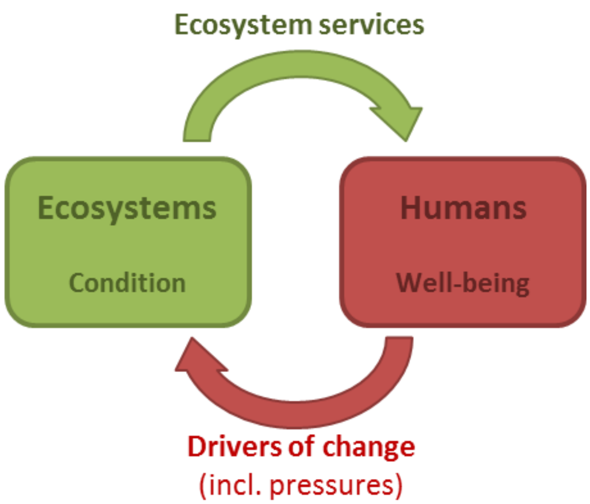

Figure 2.1. Simplified MAES conceptual model used by the pilots to develop an indicator framework for ecosystem condition. Based on Grizzetti et al. (2016).

The concept outlined in Figure 2.1 provides several entry points for developing policy relevant narratives. Environmental policy typically aims to reduce pressures on ecosystems or on the environment to create and maintain benefits. Reducing pressures can positively influence ecosystem condition and enhance particular aspects of human wellbeing such as clean water for swimming, angling and beach recreation. Policies which regulate the extraction and use of natural resources usually focus on ecosystem services (e.g. food, timber or water) but can use the concept to ensure sustainable management in multifunctional ecosystems creating co-benefits as synergy effects by providing other important services as well. The framework can also help to understand how policies which aim to enhance wellbeing (which should be the objective of policies) create pressures and have a negative impact on ecosystems and ecosystem services (trade-offs). Policies which directly target ecosystem condition (e.g. nature conservation) can use the concept to demonstrate additional benefits created by implementing conservation measures.

2.3 Requirements for indicators for ecosystem condition

The focus of this report is to propose a set of indicators for ecosystem condition per ecosystem type. In addition, the report provides a set of pressure indicators as well. Pressure indicators are considered good proxies for ecosystem condition, in particular in cases where data on ecosystem condition is scarce or not spatially explicit.

A full list of indicators for ecosystem services is available in the 2nd MAES report (Maes et al., 2014).

Condition and pressure indicators need to be scientifically sound. This means that they have to be able to measure relevant physical, chemical, or biological characteristics of an ecosystem at a particular point in time. Changes have to be visible and the selected indicator needs to reflect real changes in ecosystem condition. This is crucially important for measuring progress to the achievement of different policy targets such as the 'Aichi targets', the targets of the EU Biodiversity Strategy to 2020, or the 'Good Ecological Status' target of the Water Framework Directive.

In addition, there are several other requirements for the indicator framework (Table 2.1) so that it is useful for its application in the real world. Above all the MAES ecosystem condition indicator framework has to be policy relevant and has to contribute to the objectives of environmental legislation in the EU. The MAES indicators have to reflect policy priorities (e.g. conservation of vulnerable habitats and species), pressures on ecosystems (e.g. fragmentation of ecosystems), or the capacity of ecosystems to generate provisioning ecosystem services (sustainable food production).

Table 2.1. Requirements for the MAES indicator framework for ecosystem condition

Requirements	Description
Scientifically sound	Indicators should be based on the best available knowledge while giving a good representation of the ecosystem characteristics addressed
Supporting environmental legislation	Indicators should support the implementation of environmental legislation in the EU
Policy relevant	Indicators should be policy relevant: they have multiple policy uses and can support a policy narrative which links pressures, ecosystem condition, ecosystem services and policy objectives.
Include habitat and species conservation status	The conservation status of habitats and species (and in particular the parameters "area" and "structure and function") reported under Art.17 of the EU Habitats Directive should constitute a major indicator for assessing ecosystem condition.
Include soil related information	Terrestrial ecosystems are not in good condition if their soils are not in good condition. Specific indicators which assess the condition of soils should therefore be included.
Applicable for natural capital accounts	The indicator framework should support the development and testing of ecosystem extent and condition accounts.
Spatially explicit	Ecosystem condition is not equal across space. Different spatial gradients of pressures and differences in the response of ecosystems to pressures result in spatial variance of ecosystem condition which needs to be acknowledged in the indicator selection.
Baseline	Indicators should be measurable relative to a baseline year (e.g. 2010)
Sensitive to change	Indicators should be able to detect change over time.

Furthermore the indicators need to be quantified and stored in an accounting system. Therefore data availability is important, both in terms of baseline information, change detection as well as timeliness. Importantly, MAES promotes a spatially explicit approach taking into account that different ecosystem types require different indicators.

2.3.1 Scientifically sound indicators

A key requirement is that ecosystem condition indicators proposed in this report are based on the best available knowledge while giving a good representation of the different characteristics that shape ecosystems (physical, chemical and biological conditions). The pilot approach is set up to deliver relevant scientific input, each based on specific expert knowledge about the particular ecosystems.

2.3.2 Supporting environmental legislation

Several pieces of legislation have legally binding descriptors of the quality of specific ecosystems (or of their specific habitat types). Of particular relevance are the Birds and Habitats Directives, the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). Each of these directives determines when the conditions of habitats, species or ecosystems under their target are good: 'favourable conservation status' for habitats and species listed in the Habitats Directive, 'good ecological status' for surface waters under the WFD, and 'good environmental status' for marine water under the MSFD. The descriptors which are used in these directives need to be integrated in the MAES condition framework in order to profit from ongoing reporting streams and to minimize duplication. Usually quality descriptors (each describing a specific aspect of the environmental and ecosystem quality considered by these directives) are combined into a composite indicator such as ecological status or conservation status which is characterized by different, qualitative condition levels (e.g. good, medium, poor).

2.3.3 Relevant for different policies

The MAES condition framework has to structure the ecosystem information it collects for policy support. Therefore the links between ecosystem condition and human well-being have to be made explicit through ecosystem services and drivers of change (Figure 2.1). Through these links policies which intend to improve the condition of ecosystems and biodiversity can so demonstrate how they have a positive impact on other services for well-being. Also, policies which intend to improve well-being can use the framework to assess how they impact the condition of ecosystems and their overall capacities to provide services.

A key client is biodiversity policy. The EU Biodiversity Strategy to 2020, the EU Strategy on Green Infrastructure, the Action Plan for Nature, People and the Economy and the Seventh Environmental Action Programme will all benefit from the indicator framework to measure their implementation. The framework needs to be particularly relevant to guide investments in ecosystem restoration, green infrastructure and nature-based solutions in the EU.

Maintaining ecosystems in healthy condition so that they deliver multiple benefits through ecosystem services is a key objective of several policies which depend on natural resources, notably agriculture and forestry, fishery and water policies. Mapping and assessing the condition of ecosystems which deliver these resources can help ensure the competitiveness and sustainability of these economic sectors.

Healthy ecosystems have a direct influence on human health providing good air and water quality or opportunities to recreate and finding mental relieve. So policies which increase wellbeing by targeting public health may be inspired by the ecosystem condition indicator framework as well.

Conserving natural ecosystems and restoring degraded ecosystems provide cost effective solutions to climate change mitigation, linking also an indicator framework for ecosystem condition to climate policy.

2.3.4 Highlighting the contribution of natural habitats and of soil

The EU Habitats Directive aims to achieve a favourable conservation status for 233 different habitats (European Environment Agency, 2015b). The main habitat types correspond to a large extent to the MAES ecosystem types (see also 1st MAES report, Maes et al., 2013). Furthermore the EU Member States report every six years on the conservation status of these habitats under Art.17 of the directive. For these reasons, data on the conservation status of habitats, and in particular the parameters "area" and "structure and function", are key sources of information to assess the condition of a large part of the MAES ecosystem types.

Terrestrial ecosystems are in good condition if their soil is in good condition. Therefore, special attention in the indicator framework goes to the inclusion of indicators which assess the condition of soils for all land related ecosystems.

2.3.5 Applicable for Natural Capital Accounting (KIP INCA)

Natural Capital or Ecosystem Accounts essentially measure ecosystems and the flows of ecosystem services from these ecosystems into economic and other human activities. Ecosystem accounts therefore track the extent (or quantity) and the condition (or quality) of ecosystems (Figure 2.2). High levels of ecosystem quantity and quality will make ecosystems resilient[7] to perturbations and disturbances and at the same time provide sustainable services. Both ecosystem extent and condition define the capacity of ecosystems to provide services. When this capacity is used, ecosystem services flow from ecosystems to humans and deliver benefits. When use exceeds capacity, ecosystems are used in an unsustainable way and degrade. This is why the indicators which are used to assess the condition of ecosystems can also be used to define the potential or capacity of ecosystems to provide services.

As a part of the task in Action 5 (…'value ecosystem services and integrate them into accounting and reporting systems by 2020'), the EU is building accounts of natural capital including ecosystem extent, condition and ecosystem services (European Commission, 2016; La Notte et al., 2017). This is the objective of the Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting (KIP INCA). KIP INCA aims to work in line with the UN System of Environmental-Economic Accounting- Experimental Ecosystem

[7] Resilience can be defined as the capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions.

Accounts (SEEA-EEA)[8] and to provide feedback on how ecosystem accounting methodology can be improved based on experiences in the EU. The Technical Recommendations of SEEA-EEA make proposals on how to develop accounting tables of ecosystem extent, asset, condition and service supply and use. Associated to these accounts are thematic accounts for land, water, carbon and biodiversity.

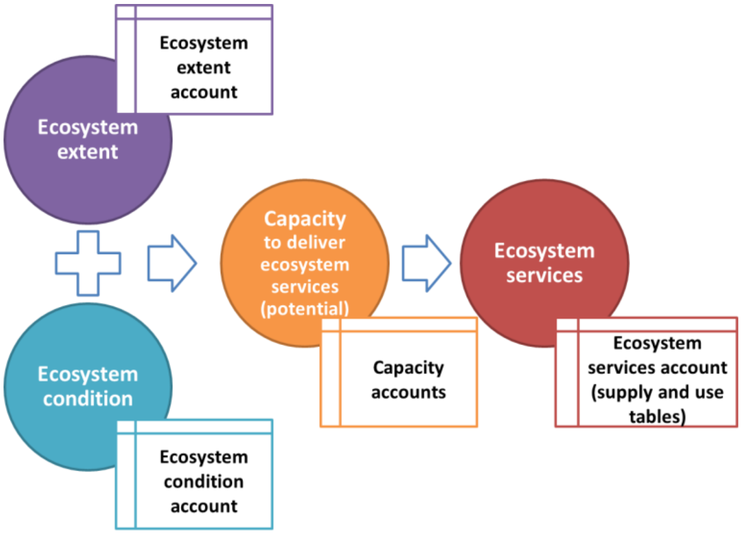

Figure 2.2. The place of ecosystem condition accounts in a natural capital accounting framework. Ecosystem extent and ecosystem condition define the total capacity to deliver ecosystem services. Using this capacity generates a flow of ecosystem services. Each of these components can be quantified in an accounting table which is coupled to other tables.

2.3.6 Spatial and temporal baselines or references for ecosystem condition

Previous studies which have assessed the integrity of ecosystems have compared the actual integrity against a reference value (distance to target). In this context, seminal work has been carried out on rivers and lakes using macro-invertebrate communities to monitor water quality. Reference communities have been sampled in pristine water bodies in order to understand how species composition, trophic levels and community structure of aquatic macro-invertebrates are organised under undisturbed conditions. In case where such pristine conditions were lacking, historical species collections have been consulted to define a reference. In cases where neither pristine conditions nor a historical reference could be found, statistical approaches and expert judgement have been used to set a reference. The measurement of ecological status of surface waters required under the WFD is a well-known example of the above mentioned approaches and could profit from decades of research and experience.

For terrestrial ecosystems potential natural vegetation models can be used to evaluate the present use of ecosystems against a modelled reference which assumes an absence of pressures (and of people).

However, in many cases 'natural' reference conditions are difficult to define and proposals result in substantial scientific debate. It is particularly difficult to define a reference condition in social-ecological systems where people and ecosystems have been closely interacting since several thousand years to co-produce ecosystem services. For example most agricultural ecosystems would not exist in Europe without human management. For that reason the SEEA EEA Technical Recommendations discuss various options for setting a reference level, one of which is based on accepting a recent historic baseline as a pragmatic choice of reference condition. In the

8 https://unstats.un.org/unsd/envaccounting/eea_project/default.asp

MAES context the choice was made to design a framework for condition to assist policy with improving the current condition of ecosystems rather than to reach a reference condition.

For this reason, the MAES framework for condition proposes that

(1) the measurement of condition depends on the current pattern of land cover, land use and management which is reflected in using the MAES ecosystem typology resulting in specific indicators and assessments per ecosystem type.

(2) the measurement of condition in 2010 can be used as a reference condition so that ecosystem condition can be assessed relative to 2010[9].

2.4 Different categories to capture the different aspects of ecosystem condition

The definition of ecosystem condition adopted in this report requires an indicator set which is able to capture physical, chemical and biological quality of the different ecosystem types while also integrating existing definitions of condition as implemented by European environmental legislation. The traditional way to assess ecosystems is to measure what ecologists call ecosystem structure (Palmer and Febria, 2012). Ecosystem structure refers to attributes that can be evaluated with point-in time measurements and that are assumed to reflect the existing condition of an ecosystem. Well known examples are the measurement of pollutant concentration, temperature, the presence of salmon in rivers, the relative composition of the different species that make up a community, or the fragmentation of a forest.

However, these attributes do not capture the dynamic properties of an ecosystem that represent its actual performance. This requires functional measurements, repeated measurements that quantify key biophysical processes. Examples are primary production or decomposition of organic material such as leaves. A functional approach to the assessment of ecosystem condition tries to address the questions "condition for what?" or "condition for which purpose?" and links ecosystem condition to ecosystem services.

Based on these ecological considerations and taking into account the definition of ecosystem condition and the different requirements of the indicator framework (Table 2.1), the classification proposed in Table 2.2 will be used in this report. A separate table for pressures on ecosystems organises the indicators according to the most important pressures on biodiversity (MA, 2005).

The table with indicators for ecosystem condition distinguishes between indicators for environmental quality (which express the physical and chemical quality of ecosystems) and ecosystem attributes (which express the biological quality of ecosystems).

[9] Note that KIP INCA considers using 2000 as baseline year for developing natural capital accounts.

Table 2.2. Hierarchical structure and classification of pressure and condition indicators

<table>
<tr><td rowspan="6">Pressures</td><td>Habitat conversion and degradation (land conversion)</td></tr>
<tr><td>Introductions of invasive alien species</td></tr>
<tr><td>Pollution and nutrient enrichment</td></tr>
<tr><td>Over-exploitation</td></tr>
<tr><td>Climate change</td></tr>
<tr><td>Other pressures</td></tr>
</table>

<table>
<tr><td rowspan="7">Ecosystem Condition</td><td>Environmental quality (physical and chemical quality)</td><td colspan="2"></td></tr>
<tr><td rowspan="6">Ecosystem attributes (biological quality)</td><td rowspan="4">Structural ecosystem attributes</td><td>Structural ecosystem attributes (general)</td></tr>
<tr><td>Structural ecosystem attributes based on species diversity and abundance</td></tr>
<tr><td>Structural ecosystem attributes monitored under the EU nature directives</td></tr>
<tr><td>Structural soil attributes</td></tr>
<tr><td rowspan="2">Functional ecosystem attributes</td><td>Functional ecosystem attributes (general)</td></tr>
<tr><td>Functional soil attributes</td></tr>
</table>

2.4.1 Pressures and environmental quality indicators

Most observers agree that pressure indicators should be part of an ecosystem condition assessment framework. There is, however, a conceptual difference between pressures and environmental quality. Pressures cause a decrease in environmental quality. Decreasing pressures indicate improvements of condition. Environmental quality indicators typically tell us that there is something wrong in the ecosystems (or in the environment) while pressure indicators tell us why something is wrong. An increase in pressure indicators is usually negatively related to ecosystem condition. Ecosystems usually don't react immediately to changes in pressures but have quite a response time. So both are relevant to measure and policy relevant.

Pressures range between low and high levels and so, too, varies their impact on ecosystems. When pressures are very low, they are likely to cause little, or sometimes unmeasurable change in ecosystem condition. Increasing the level of pressures can have different impacts on ecosystem condition depending on the kind of pressure, whether or not different pressures act simultaneously and on the particular response of ecosystems. For instance, habitat loss may affect a fish stock in a linear way leading to a gradual decrease of the population but harvesting beyond a sustainable level of the fish stock may result in abrupt and non-linear population changes.

Pressure indicators are measured in units per unit time, for instance the amount of nitrogen deposited on a forest over the course on one year (kg N/ha/year). Indicators of environmental quality are based on point in time measurements, for instance the concentration of nitrogen in a litre of lake water (mg N/l).

Given the strong causal relation between pressures and ecosystem condition, pressures can be used as indicators to approximate condition in cases where indicators for ecosystem condition are not available. Changes in pressures indicate expected changes in condition but don't include important processes of ecosystem resilience such as buffering capacities, or decomposition of toxic substances which can only be addressed by direct measurements of ecosystem condition and its changes over time

2.4.2 Ecosystem attributes

Ecosystem attributes refer to both structural and functional indicators. This corresponds well with the ecosystem services cascade concept as structure and function both contribute to ecosystem condition and to the provision of services.

For the reasons explained earlier, some indicators receive special attention because of their role in policy or because of their relevance for ecosystem condition. This is the case for structural ecosystem attributes based on species diversity and abundance, for indicators derived from the assessment of conservation status of habitats and species under Art.17 of the Habitats Directive and for soil indicators.

2.4.3 Composite indicators

The current proposals contain both single and composite indicators for ecosystem condition. Composite indicators are available for ecosystem types which are covered by the Habitats Directive (conservation status), the WFD (ecological status) and the MSFD (environmental status). They are based on a compilation of individual metrics.

Ultimately, for every ecosystem type a composite indicator could be developed to assess its condition but such a proposal is not included in this report.

The development of a single, aggregated indicator on ecosystem condition needs to be based on an analysis of the data underpinning the indicators and would benefit from stakeholder involvement to warrant a proper weighting of individual metrics.

3 WORKING PROCEDURES AND ANALYTICAL FRAMEWORK

3.1 Set up of the pilot studies

The indicators proposed in this report are based on the work delivered by the MAES ecosystem pilots. Each ecosystem pilot consists of a group of experts who have particular knowledge in a certain area: forests, agro-ecosystems, urban ecosystems, freshwater ecosystems, marine ecosystems, nature, and soil. The choice for these particular pilot studies was based on sectoral policy needs, expertise which is documented e.g. in the second MAES report (Maes et al., 2014) but also considered the specific organization of knowledge inside different European institutions and services.

During 2017 the pilots followed a common roadmap to prepare this report (Figure 3.1). The work started in January 2017 with a workshop which delivered a paper with working procedures for the pilots. Feedback from the Member States and from different units of the European Commission and the European Environment Agency was used to consolidate the condition framework.

All materials which were used to prepare this report are available on CIRCA BC and include the proposal for an analytical framework for ecosystem condition, a background document, a discussion note on the refinement of the analytical framework, and a series of tables in MS Excel with the indicators.

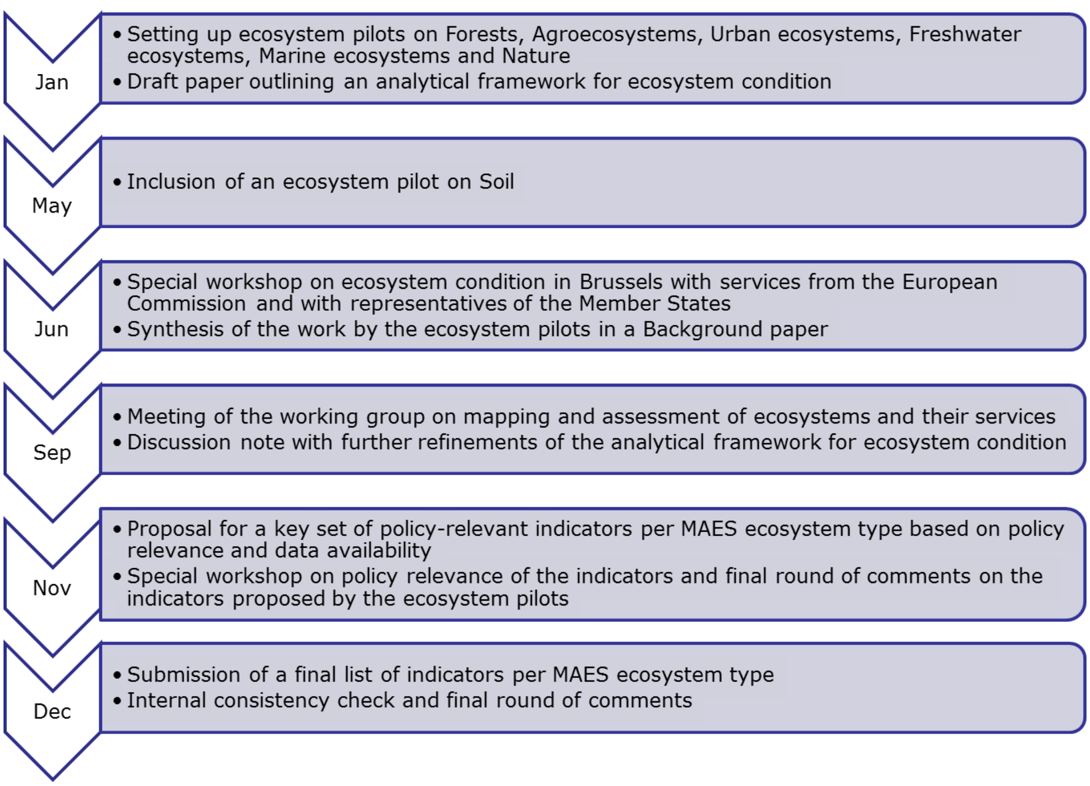

Figure 3.1. Roadmap to the MAES ecosystem condition indicator framework.

3.2 Indicator selection procedure

A final selection of indicators which is proposed in this report was achieved after taking the following steps:

1. Every pilot made a proposal with indicators for pressures and ecosystem condition; the nature pilot included specific indicators for heathland and shrub, sparsely vegetated land and wetlands and made also proposals for the inclusion of specific indicators in other ecosystem pilots. The soil pilot made proposals for the inclusion of specific soil indicators into the other pilots. These proposals were based on different approaches including literature review and expert meetings. More specific details per ecosystem pilot are available in the Background paper on CIRCA BC.
2. A first revision of the proposals for indicators was based on the input of about 90 experts from the Member States and EU services during a two day workshop. This revision resulted in the inclusion of indicators which were initially overlooked by the pilots. Furthermore the workshop identified priority indicators (indicators with high policy relevance). The analytical framework was overall accepted but some refinements were proposed.
3. Following this workshop a second revision of the proposals for indicators was based on a comparison across the different ecosystem pilots. This second revision (based on a discussion note on the refinement of the analytical framework) ensured that the indicators of the different pilots were internally consistent (i.e. using a similar classification for indicators).
4. A third revision was based on a consultation of potential policy users of the indicator framework and resulted in a final list of indicators per ecosystem type.

3.3 From ecosystem pilots to ecosystem types

The final indicator tables refer to each of the 12 MAES ecosystem types at level 2 (7 terrestrial types, 1 freshwater type and 4 marine types; see 1st MAES report page 25-27; Maes et al., 2013). Figure 3.2 shows how the different pilot studies provided their expert knowledge to deliver a final set of indicator tables. Note the different roles of both the soil and nature pilots with respect to the other ecosystem pilots.

The nature pilot developed the indicator framework for three biodiversity-rich ecosystem types not covered by any other pilot but provided also indicators for all other ecosystem types. Due to their sectorial specificities, the other ecosystem types mainly 'Grasslands', 'Croplands', 'Forest and woodland', 'Freshwater' and 'Marine' are covered by the respective thematic ecosystem types with the Nature pilot contributing data and indicators from the respective Directives. Therefore there are mutual cross-links between the Nature ecosystem types and the other thematic ecosystem types mainly agriculture, forest, freshwater and marine. Note also that groundwater is included in the Freshwater pilot.

The soil pilot proposed indicators for all the terrestrial ecosystem types. The indicator for soil biodiversity (species richness and relative abundance) is based on the analysis of soil DNA extracted from over 1,000 sites across Europe and will be available in 2019 as part of LUCAS Soil survey.

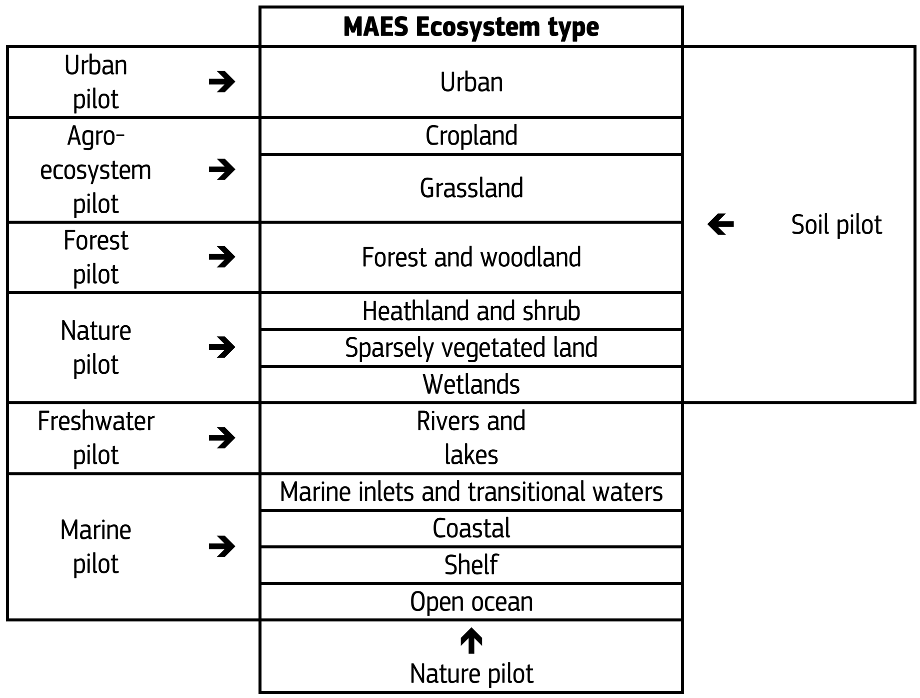

Figure 3.2. Contribution of the different MAES pilots to the final indicator framework.

3.4 Final indicator tables

The result of the work by the different pilots is a list of indicators of pressures and ecosystem condition per MAES ecosystem type. For the purpose of simplification, grassland and cropland (agroecosystems), transitional waters and coastal, and shelf and open ocean (marine ecosystems) are reported together.

3.4.1 Consistent classification of indicators

Every indicator table contains a set of indicators organized using the same indicator classes (see table 2.2). A consistent classification improves the applicability of the indicator framework for horizontal and integrated ecosystem assessments (see 3.5).

Every indicator is reported with its units. In case there are no units, the indicator refers to an index (for instance between 0 and 1) and is thus dimensionless.

3.4.2 Key indicators

Some indicators are printed in bold in the indicator tables. These indicators are considered key indicators for mapping and assessment of ecosystem condition. They are selected by taking together two criteria: policy relevance and data availability.

Policy relevant indicators are indicators with at least two identified policy uses. Policy use is determined by the fact that the indicator is already part of another indicator framework. So the different pilots analysed every indicator and checked whether or not it was relevant for the following policies: the EU Biodiversity Strategy to 2020, the Nature directives (Habitats and Birds directives), the Marine Strategy and Water Framework directives, the Sustainable Development Goals, and other directives or strategies which are relevant for the considered ecosystem type e.g., the EU Forest Strategy. In addition, a second screening of policy uses was performed based on a table which lists indicator sets which monitor 19 specific (environmental) policies or existing indicator frameworks of the European Commission, including the SEBI (Streamlining European Biodiversity Indicators), AEI (Agri-Environmental Indicators), the circular economy, resource efficiency and climate actions sets. For forests also indicators from the Forest Europe process (of which the EU is signatory) were considered (FOREST EUROPE, 2015). The pilots checked whether or not the indicator appeared in one of these strategic planning and monitoring frameworks.

A second criterion used for identifying key indicators is data availability. Two conditions qualify: baseline data for the year 2010 and the possibility to evaluate the value of the indicator relative to the baseline for at least point in time. Preferably, more data is available to establish a trend for the indicator.

The scores per indicator for policy use and data availability are reported in MS Excel spreadsheets on CIRCA BC. Also the table with indicator sets which monitor 19 specific policies or existing indicator frameworks is made available as online supplement.

3.4.3 Special remarks

The indicator tables include also the following information:

- Whenever the indicator is part of the SEBI or AEI indicator frameworks it is mentioned between brackets. The tables for marine ecosystems contain a code for indicators which are reported under the MSFD.
- Indicators in red are indicators for which data coverage is not guaranteed at European level. However, they are still included in the indicator framework as experts believe that European wide data collection of these indicators would considerably enhance our knowledge of ecosystem condition.
- Composite indicators are recognized by the abbreviation "CI".
- All indicator tables contain special remarks in a note under the table.

The notation of units of indicators is not using the superscript for square (2) or cubic (3) units or for units in the denominator (-1 or -2). This is to increase readability of the units in the tables (which have a smaller font size) and to ensure consistency with the supplementary information in MS Excel. Example: the volume of wood per square km is thus noted as m3/km2 instead of m^3/km^2 or $m^3\ km^{-2}$). Whenever the unit tonne is used it equal to 1,000 kg.

3.5 How to read and use the indicator tables

The set of indicators proposed in this report represents the best available knowledge to map and assess ecosystem condition at EU level. The tables can be used to assess the pressures and condition of individual ecosystem types but they can also be used to look at ecosystem condition horizontally across ecosystems. For instance, an assessment of the condition of soil in Europe would be based on the different soil indicators across the terrestrial ecosystem types. Similarly, an assessment of environmental (or abiotic) quality can be based on the combination of the different indicators for this class across all ecosystem types.

The combination of all the key indicators will contribute to the delivery of an integrated ecosystem assessment and to the final evaluation of the EU biodiversity targets to 2020.

The set of indicators proposed in this report needs to assist EU level policy making and implementation. So in first instance, the indicators are selected to assess ecosystems at EU level. However, many of the indicators are scalable or they are derived from information at national or regional level and can thus be used for national assessments as well.

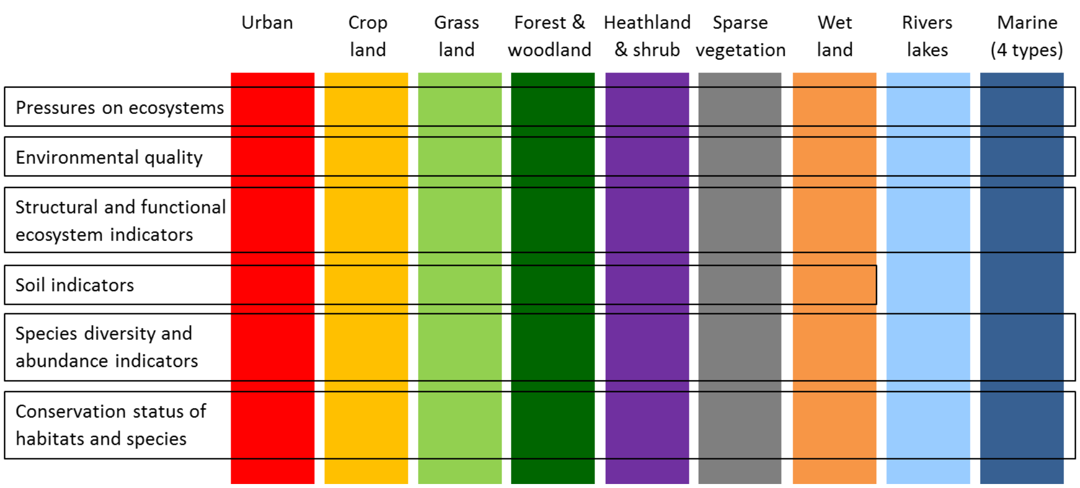

Figure 3.3. How to use the different indicator tables. A vertical ecosystem assessment with a set of indicators per ecosystem type or a horizontal assessment of ecosystem condition across different ecosystem types

4 INDICATORS FOR MAPPING AND ASSESSING ECOSYSTEM CONDITION PER ECOSYSTEM TYPE

This chapter is the core of this report. It proposes a set of indicators per ecosystem type for mapping and assessment of the conditions of the 12 MAES ecosystem types. In addition, it includes per ecosystem type a table with indicators for the pressures on ecosystems. Additional information and supplementary material is available on CIRCA BC.

4.1 Urban ecosystems

An urban ecosystem is the ecological system located within a city. Like any other ecosystem urban ecosystems are composed of physical and biological components that interact with each other. Consequently, indicators which measure the condition of urban ecosystems as well as the pressures acting on them cover both the built and green infrastructure which together constitute cities.

Urban ecosystems are considered in a good condition if the living conditions for humans and urban biodiversity are good (Maes et al., 2016). This means, among others, a good quality of air and water, a sustainable supply of ecosystem services and a high level of urban species diversity.

The collection of indicators to measure pressures and condition in urban ecosystems is based on the MAES urban pilot (Maes et al., 2016) and underwent several rounds of review (see Chapter 3). Table 4.1 presents all the indicators assorted over different pressures and different high level categories of condition. This table is thus an updated version of table 18 of the 4th MAES report on urban ecosystems (Maes et al., 2016).

Important pressures on urban ecosystems are unsustainable land take, air and water pollution, noise, and unwanted introductions of invasive alien species. Land take is, in general, a pressure on other ecosystem types which are converted in the artificial areas. It is relevant for urban ecosystems in case of conversions of natural and semi-natural habitats to artificial land within the boundaries of urban areas (see Maes et al., 2016 for delineation of urban ecosystems). Air quality and noise are important environmental concerns in cities with impacts human health so indicators are available to measure these pressures as well.

The condition indicators for environmental quality of urban ecosystems cover urban temperature, air and water quality, noise levels, and different metrics which assess the share, types and composition of built area in relation to population density. The condition indicators for ecosystem attributes are based on the spatial coverage, the configuration and the state of the urban green space and urban vegetation. Special attention goes to the share of protected area inside the boundaries of cities. This can be measured by intersecting the area of Natura 2000 sites or of other protected areas with a map of the spatial extension of cities. Also biodiversity indicators, in particular birds, can be part of the indicator framework.

The condition of soil in urban ecosystems can be measured by considering soil compaction (bulk density), soil contamination, organic carbon stock or soil biodiversity.

Table 4.1. Indicators for pressures and condition of urban ecosystems

Pressures	
Habitat conversion and degradation (Land conversion)	**Land annually taken for built-up areas per person (m2/person/year)**
	Soil sealing (ha/year)
Climate change	Number of combined tropical nights (above 20 °C) and hot days (above 35 °C) (number/year)
Pollution and nutrient enrichment	**Emissions of NO2, PM10, PM2.5 (kg/year)**
	Number of annual occurrences of maximum daily 8 hour mean of O3 > 120 µg/m3 (number/year)
	Number of annual occurrences of 24 hour mean of PM10 > 50 µg/m3 (number/year)
	Number of annual occurrences of hourly mean of NO2> 200 µg/m3 (number/year)
	Number of annual occurrences of (traffic) noise at levels exceeding 55 db(A) during the day and 50 db(A) during the nights (possibly broken down over the source of noise) (number/year)
Over-exploitation	n.a.
Introductions of invasive alien species	Number of annual introductions of invasive alien species* (number/year)
Ecosystem condition	
Environmental quality	Urban temperature (°C)
	Noise levels (dB(A))
	Percentage of population exposed to road noise within urban areas above 55 dB during the day and above 50 dB during the night (%)
	Percentage of population exposed to air pollution above the standards (%)
	Concentration of air pollutants NO2, PM10, PM2.5, O3 (µg/m3)
	Concentration of nutrients and biological oxygen demand in surface water (mg/l)
	Bathing water quality (quality levels)
	Percentage of population connected to urban waste water collection and treatment plants (%)
	Number of inhabitants per area (number/ha)
	Artificial area per inhabitant (m2/person)
	Length of the road network per area (km/ha)
	Percentage of built-up area (%)
	Weighted Urban Proliferation (Urban Permeation Units/m2)
	Imperviousness (%)
	Sites with contaminated soil (number)
Ecosystem attributes	
Structural ecosystem attributes (general)	**Percentage of urban green space (%)**
	Percentage of natural area (%)
	Percentage of agricultural area (%)
	Percentage of abandoned area (%)
	Canopy coverage (ha)
	Foliage damage crown dieback (number of trees affected)
	Connectivity of urban green spaces (%)
	Fragmentation of urban green space (Mesh density per pixel)
Structural ecosystem attributes based on species diversity and abundance	Number and abundance of bird species (number; number/ha)
	Number of lichen species (number)
	Number of invasive alien species (number)
Structural ecosystem attributes monitored under the EU nature directives	**Percentage of urban ecosystems covered by Natura 2000 area (%)**
Structural soil attributes	Bulk density (kg/m3)
	Soil organic carbon (SOC) (g/kg)

	Soil biodiversity (DNA-based richness and abundance)
	Earthworms (number, number/ha)
Functional ecosystem attributes (general)	n.a.
Functional soil attributes	Available water capacity (mm/year)

Table notes: Indicators printed **in bold** are key indicators (see also section 4.1.1).; n.a.: not available or not applicable; *This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

One functional indicator is part of the framework for urban ecosystems: available water capacity which measures how much water an urban soil can store. This indicator links directly to water regulation in cities. Note that indicators for ecosystem services are proposed in the 4th MAES report on urban ecosystems and are not repeated here. But they cover different functions of urban ecosystems.

The indicators listed in Table 4.1 can be measured or quantified within the spatial extent of the city. The 4th MAES report on urban ecosystems outlines several scales and boundaries which are relevant for an urban ecosystem assessment ranging from regional scale to census blocks. The report also outlines the possible boundaries or the spatial extents of cities which can be used for an assessment. An EU wide assessment should preferentially use the Functional Urban Areas (FUAs) as spatial unit of assessment and calculate the pressure and condition indicators within these boundaries (rather than using political boundaries). FUA is a unified typology for delineating cities in Europe taking into consideration population density. This ensures an unbiased comparison of the performance of different cities. This is particularly important for indicators which assess the percentage (%) or relative surface area such as the percentage of urban green space.

4.1.1 Key indicators

Not all the indicators of Table 4.1 have equal policy uses and equal data coverage. Some indicators are already reported under other policy frameworks. The indicators in bold are considered key indicators for pressures and condition of urban ecosystems. These are the indicators with at least two policy uses and for which a baseline and time series of data is available at European scale. For pressures two indicators are retained: land take and emissions of air pollutants. The table with condition indicators contains 10 key indicators. They relate to noise, air quality, water quality, and waste in terms of environmental quality. The share of urban green space and the percentage of natural areas are key structural indicators. Also birds and coverage by Natura 2000 are among the set of key indicators for urban ecosystem condition.

4.1.2 Example of an application of the indicator framework in urban policy

Figure 4.1a presents a synthesis of the different links between pressures, condition and ecosystem services in an urban ecosystem. It contains the 4 main components of the conceptual framework but this time they are put next to each other.

Different relations between pressures and condition emerge. Land take has an impact on all the indicators. Conversion of land into artificial areas is a pressure on all terrestrial ecosystem types but also within the boundaries of cities it affects the average urban temperature, noise levels, air quality or the amount of urban green space. Air and water pollution have more specific impacts whereas noise and the introduction of alien species have a one to one relationship with noise levels and species diversity, respectively.

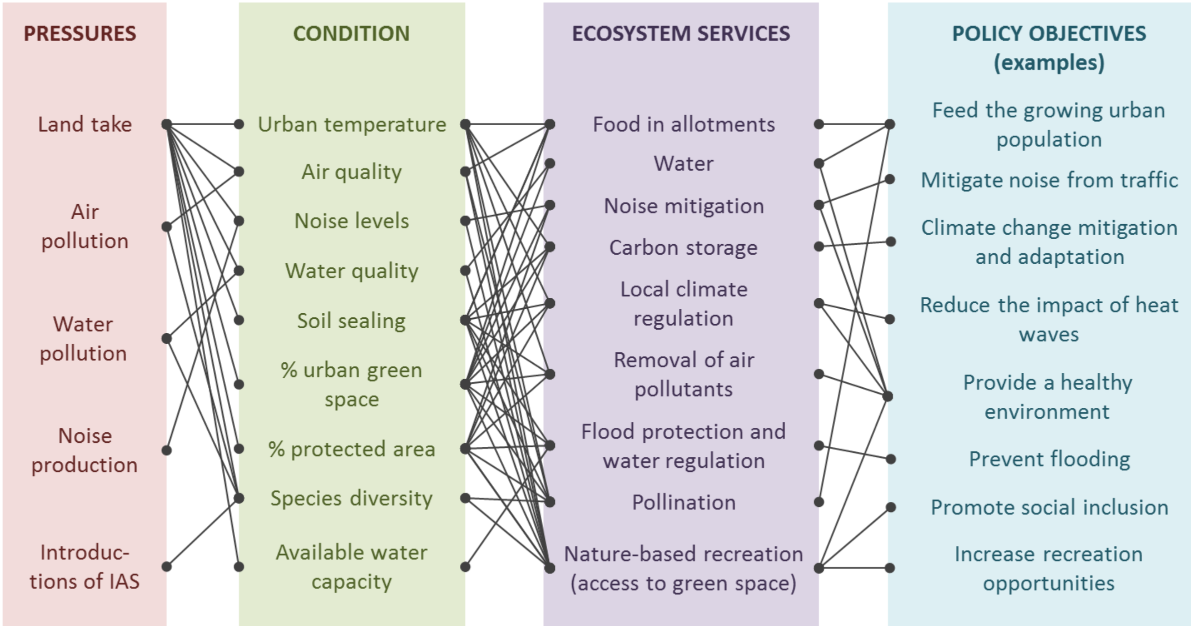

Figure 4.1. Synthesis of the links between pressures, condition and ecosystem services in urban ecosystems.

Ecosystem condition is strongly connected to the delivery of various urban ecosystem services. Consider for example urban temperature which is a key parameter for many ecological processes and thus also for the provision of ecosystem services. The same can be said for the percentage of urban green space which may be the single most important determinant for urban ecosystem services. Urban ecosystem services enhance human wellbeing and can thus be connected to different policy objectives. The box on the right hand side contains examples of such policy objectives and is not exhaustive.

Figure 4.1b shows only the nodes and links if the policy objective is to reduce the impact of heat waves. In summer cities are warmer than the surrounding peri-urban or rural areas. This is known as the urban heat island effect. In particular during heat waves this can lead to thermal discomfort among the population or worse, serious health impacts and increased mortality. Many cities have therefore a policy and targets to reduce maximum summer temperature.

Clearly, a policy on urban temperature needs to encompass actions with respect to human health, prevention of impacts, and a focus on vulnerable groups but the present indicator framework can help identify how ecosystems can help reduce the impact of heath waves in cities. Enhancing local climate regulation in cities is a key component of such an action plan. Trees and shrubs have a cooling impact on the surrounding neighbourhood by providing shade and by evaporating ground water. Monitoring urban temperature, soil sealing, the percentage and composition of urban green space and the rate of land take at the cost of ecosystems with a cooling capacity are key indicator to inform decision making.

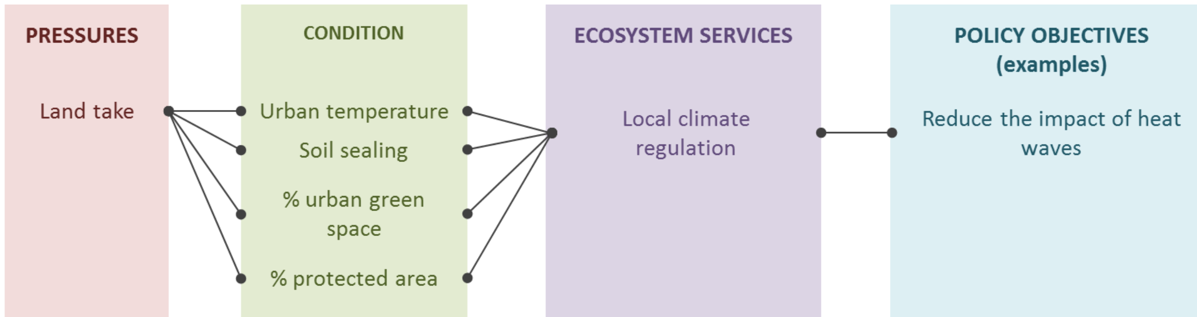

Figure 4.1b. Extraction of the nodes and links of Figure 4.1a to illustrate the example of reducing the impact of heat waves.

4.2 Agroecosystems

Agricultural land use is the primary land use in the European Union, accounting for 45% of its total area. The ecosystem type addressed in this section is agroecosystems, intended as communities of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fibre, fuel and other products for human consumption and processing (Altieri, 1971). The MAES process has so far classified agroecosystems into cropland and grassland ecosystems (Maes et al., 2013). Cropland is the main food production area including both intensively managed ecosystems and areas under lower intensity management, supporting semi-natural vegetation along with food production. It includes regularly or recently cultivated agricultural, horticultural and domestic habitats (incl. associated landscape elements) and agro-ecosystems with significant coverage of natural vegetation (agricultural mosaics). Grassland covers areas dominated by grassy vegetation (but including tall forbs, mosses and lichens) of two kinds – intensively managed pastures and fodder production, and semi-natural (extensively managed) grasslands.

Agriculture was introduced in Europe about 9000 years ago, and in a period of four millennia it has spread all over the continent. In the following 5000 years until today it has shaped and changed the face of European landscapes. Due to the prolonged interaction between natural and human systems, which is characteristic of agriculture, the definition of good condition for agroecosystems cannot be solely based on physical and ecological properties of soils and plants. The definition must also address the disturbance introduced by humans, altering the functioning of agroecosystems. Moreover, the definition has to account for the question how agroecosystems can continue to support human life, and provide the manifold services we all are dependent on.

Agroecosystems are modified ecosystems, they are in good condition when they support biodiversity, abiotic resources (soil-water-air) are not depleted, and they provide a balanced supply of ecosystem services (provisioning, regulating, cultural). Sustainable management is key to reaching or maintaining a good condition, with the aim to increase resilience and maintain the capacity of delivering services to current and future generations.

Table 4.2 presents the indicators to measure pressures and condition of agroecosystems. These are split between cropland and grassland ecosystems. In some cases indicators exist that address specifically each of the two ecosystem types (i.e. grassland habitat fragmentation, crop diversity), in other cases they can be calculated by masking a spatially distributed layer with a mask derived from Corine Land Cover (i.e. soil organic carbon, soil erosion), in some other cases it is not possible to make the distinction. In this latter case, the availability of one single indicator is marked with a "Y", across the two columns. In some cases indicators are not applicable, which is marked by "NA". Typical cropland related indicators for instance are not applicable on grassland and vice versa.

Major pressures on agroecosystems include habitat conversion spanning from the sealing of agricultural soils to changes in intensity of farming systems; climate change, which is heavily impacting on yields, growing patterns and crop distribution; pollution and nutrient enrichment, described by the use of nitrogen, phosphorus and pesticides; overexploitation, which includes information on the use of water and the degree to which agricultural land use alters energy flows in ecosystems via land conversions and especially biomass harvest (HANPP indicator – Human Appropriation of Net Primary Production; Krausmann et al., 2012). Introduction of invasive alien species, soil erosion and loss of organic matter in soil complete the picture.

The condition indicators for environmental quality describe the quality of water and soil in relation to the presence of nitrogen and pollutants. General structural attributes aim at describing the factors that enhance management sustainability and therefore support (or hinder) the multiple provision of ecosystem services: the structure of cultivated and semi-natural vegetation in agricultural areas (here assessed with the indicators crop diversity, presence of semi-natural elements and their connectivity, degree of habitat fragmentation, presence of fallow land), the presence of areas under management practices potentially supporting biodiversity (organic farming and HNV farmland), the presence of livestock as a factor that can support a good condition (High Nature Value –HNV- farmland), or vice versa can accelerate habitat degradation.

A consistent number of indicators refers to species and habitats of Community interest in terms of conservation status and extent. Farmland birds, grassland butterflies and pollinators are addressed individually as established indicators to describe biodiversity trends in agricultural lands. Soil structural attributes relevant for agriculture are described through five indicators (soil organic carbon content, pH, soil erodibility – i.e., risk to be eroded –, bulk density and soil biodiversity). Functional attributes describe availability of water and productivity. Soil related parameters in this section include water and nutrients availability.

The listed indicators may be available at different resolutions, ranging from the parcel (IACS/LPIS data[10]) to Member State level. The ideal resolution for assessing agroecosystems condition at EU level spans from 1 to 10 km grids. Information at a lower spatial resolution (NUTS2 to NUTS0), especially if available in trends, complements the narrative.

Three indicators of Table 4.2 are printed in red (and marked with an "N"). These indicators are not available but would complement the existing indicator set. Consider pesticide use. Data on the sales of pesticides are available at national level but an assessment of ecosystem condition would benefit from measurements of the actual application of pesticides at field level. However, there is no consistent monitoring of pesticide application at EU level. Another useful indicator, linked to pesticide use, would be the frequency of pest and disease outbreaks. Note that this indicator is partly placed under introductions of invasive alien species as some pest species are not indigenous.

[10] The Integrated Administration and Control System (IACS) and Land Parcel Identification System (LPIS) are used in the implementation process of the EU Common Agricultural Policy

Table 4.2. Indicators for pressures and condition of agroecosystems

Pressures		Cropland	Grassland
Habitat conversion and degradation (Land conversion)	**Land take (%/year)**	Y	Y
	Change in ecosystem extent (%/year) (SEBI004) (AEI10.1)	Y	Y
	Intensification / extensification (AEI12)	Y	Y
Climate change	Change in climate parameters (including drought): long term changes (>=30-year)	Y	
	Past trend in summer soil moisture content (l/m3/10 years)	Y	
Pollution and nutrient enrichment	Nitrogen deposition (kg/ha/year)	Y	Y
	Gross nitrogen balance kg/ha/year (SEBI 019) (AEI15)	Y	Y
	Gross phosphorus balance (kg/ha UAA/year) (AEI16)	Y	
	Mineral fertilizer consumption (kg/ha/year) (AEI5)	Y	Y
	Pesticide use (kg active ingredient/ha/year)	N	N
Over-exploitation	Water abstraction (million m3/year) (AEI20)	Y	
	Human Appropriation of Net Primary Production (HANPP) (kg C/m2/year)	Y	Y
Introductions of invasive alien species	Number of annual introductions of invasive alien species* (number/year)	Y	
Others	Frequency of pest and disease outbreaks	N	N
	Soil erosion (tonne/ha/year) (AEI21)	Y	Y
	Loss of organic matter [%SOC/year]	Y	Y
Ecosystem condition		**Cropland**	**Grassland**
Environmental quality	Nitrogen concentration in surface and groundwater in Nitrogen Vulnerable Zones (mg/l)	Y	Y
	Heavy metal concentrations in soil (mg/kg)	Y	Y
Ecosystem attributes			
Structural ecosystem attributes (general)	Grassland habitat fragmentation (meshes/1000 km2)	NA	Y
	Landscape fragmentation index (index)	Y	Y
	Crop diversity/ 10 km×10 km (number)	Y	NA
	Crop rotation (functional crop groups) (number)	Y	NA
	Density of semi-natural elements (%/ha)	Y	Y
	Connectivity of semi-natural elements (index)	Y	Y
	Share of fallow land in UAA (%)	Y	
	Share of High Nature Value farmland in agricultural area (%) (SEBI 020) (AEI23)	Y	Y
	Share of organic farming in UAA (%) (SEBI 020) (AEI4)	Y	
	Livestock density (LU/ha)	Y	
Structural ecosystem attributes based on species diversity and abundance	**Farmland Bird Indicator (index) (SEBI 001) (AEI2.4.1)**	Y	
	Grassland Butterfly Indicator (index) (SEBI 001)	NA	Y
	Mammals, amphibians, reptiles impacted by changes in agriculture (Red List index)	N	N
	Wild pollinators (where available) (species richness)	Y	
Structural ecosystem attributes monitored under the EU nature directives	**Conservation status and trends of habitats of Community interest associated to grassland (%)**	NA	Y
	Percentage of agroecosystems covered by Natura 2000 (%)	Y	Y
	EU Population status and trends of bird species associated to cropland and grassland (%)	Y	Y
	Conservation status and trends of species of Community interest associated to cropland and	Y	Y

	grassland (%)		
Structural soil attributes	**Soil organic carbon (SOC) (% or g/kg)**	Y	Y
	Soil pH (pH)	Y	Y
	Soil erodibility [K-factor (tonne ha h/MJ mm)]	Y	Y
	Bulk density (kg/m3)	Y	Y
	Soil biodiversity (DNA-based richness and abundance)	Y	Y
Functional ecosystem attributes (general)	Water availability (m3/ha/year)	Y	
	Gross primary production (kJ/ha/year)	Y	Y
Functional soil attributes	Available water capacity (index)	Y	Y
	Soil nutrients availability (nitrogen & phosphorus) (mg/kg)	Y	Y

Table notes: Indicators which will become available in 2018-2019 are accounted for; Indicators are accounted for policy relevance also if part of the indicator is present in the reference framework (i.e. conservation status of grasslands vs conservation status of habitats); Y = available indicator, either individually for each of the two considered ecosystem types, or as one indicator (Y across the two columns) to be further split into cropland and grassland i.e. by masking on the basis of Corine Land Cover; N: Not available (these indicators are also printed in red, see section 3.4.3); NA: Not Applicable; UUA: Utilized Agricultural Area; SEBI: Indicator of Streamlining European Biodiversity Indicators; AEI: Agri-Environment Indicator; Indicators printed **in bold** are key indicators (see also section 4.2.1); *This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

4.2.1 Key indicators

Some of the indicators in Table 4.2 are already reported under other policy frameworks and the table summarises their policy relevance. Indicators are marked in bold when they are present in at least two established policy frameworks and when a baseline and time series of data is available at European scale. For pressures five indicators fulfil these criteria: land take, intensification/extensification trends, nitrogen and phosphorus balance, loss of organic matter. In the table on condition, 10 indicators are highlighted: landscape fragmentation, livestock density, areas under management practices potentially supporting biodiversity (HNV farmland and organic agriculture), soil organic carbon, farmland bird index and four indicators linked to reporting under nature legislation.

4.2.2 Example of an application of the indicator framework in agricultural policy

The impacts of agriculture are manifold. If on the one hand low intensity farming practices enhance biodiversity (i.e. HNV farming) and provide a more balanced supply of ecosystem services, intensive agriculture can have major impacts on biodiversity, soil, water, air and climate. As a consequence of this, policy objectives in both, the EU Biodiversity Strategy to 2020 and in the EC Communication outlining ideas on the future of food and farming (European Commission, 2017) highlight the need to enhance the positive contribution of the agricultural sector to biodiversity and sustainable use of resources, including a reinforced commitment to the delivery of public goods and ecosystems services related to soil, water, biodiversity, air quality, climate action and the provision of landscape amenities.

Figure 4.2a lists pressures, agroecosystems condition attributes, and ecosystem services that depend on agricultural practices or services on which agriculture has an impact, together with the main and broad policy objectives that need to be addressed by the agricultural sector. The system is very complex and it is not possible to add in the figure all the links that relate pressures that need to be reduced, to the attributes of agroecosystem condition that would be positively affected, to the ecosystem services that would be enhanced, and finally, to the policy goals that would be reached through this causal chain.

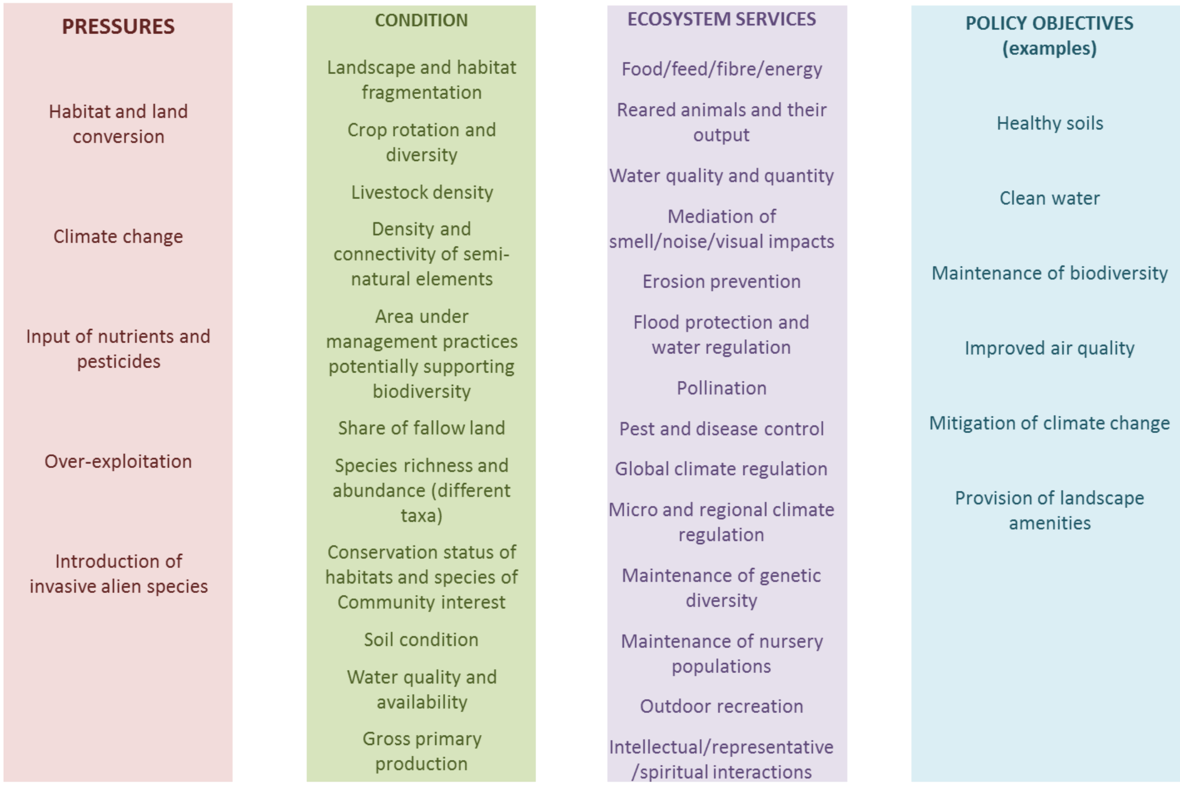

Figure 4.2a. Synthesis of pressures, condition and ecosystem services in agroecosystems.

Identifying a specific policy objective illustrates how the framework can be applied. The presented example (Figure 4.2b) identifies as policy goal avoiding the decline of pollinators. This is directly linked to the ecosystem service pollination. The attributes of agroecosystem condition that affect the delivery of the ecosystem service depend on, among others, the presence of crops providing floral resources to pollinators (including certain types of fallow land); the presence of elements of semi-natural vegetation providing both floral resources and nesting sites; a high richness and abundance of wild flowers and also a high richness and abundance of pollinator species; a good conservation status of habitats of Community interest providing floral and nesting resources to pollinators (i.e. various grassland habitats); a low degree of habitat fragmentation, agricultural practices of low intensity or characterized by a reduced use of pesticides (i.e. organic farming). In this case, all five main typologies of pressures differently affect these condition attributes, and therefore all have a role to play in order to reach the identified policy objective; implications for designing policy instruments can thus be drawn.

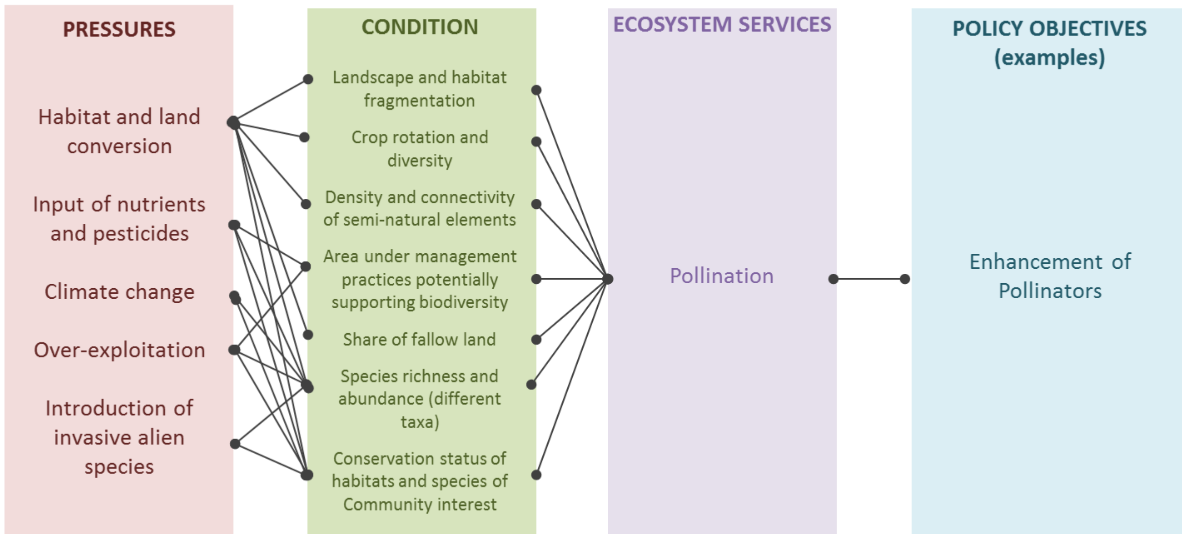

Figure 4.2b Extraction of the nodes of Figure 4.2a to illustrate the example on how to enhance pollinators.

4.3 Forests and woodland

Forests and woodland cover around 40% of EU's land area and are home to much of the European biodiversity. Likewise, forests deliver multiple ecosystem services supporting and satisfying human needs. Consequently, society benefits from forest services while at the same time modifies forest ecosystems through a number of direct and indirect pressures, for instance land use, climate change, air pollution and invasive alien species contribute to shape the condition of forests. Despite the amount of available information on forest ecosystems from ground surveys (e.g. National Forest Inventories) and remote sensing, assessing forest condition remains challenging. First, there is lack of consensus regarding a definition of forest condition or health that can be operationalised with available indicators. Second, although indicators of forest condition are available, these are in some cases either limited in time, spatial scale or are relative to few dimensions of forest ecosystems.

Forest condition (health and vitality) can be defined based on the combined presence of abiotic and biotic pressures and the way they affect tree growth and survival, the yield and quality of wood and non-wood products, wildlife habitat, recreation and scenic and cultural values (FAO, 2017). The capacity of providing non-wood products and other forest services is central for understanding the condition of forests. In fact, the condition of forests affects their capacity to provide ecosystem services. Therefore, the discussions on forest condition are tightly connected to concepts of sustainability, resilience and ecosystem functions, and with humans and their activities being an integral part of the system (Innes & Tikina, 2017; Seymour & Hunter, 1999). Human expectations can be met if the forest is resilient, is managed in a sustainable way and functions within the ecosystem boundaries.

Forest condition can be approached as a function of the extent to which ecosystem processes are functioning within natural historical boundaries and using appropriate modifiers to specify the scales and/or human expectations (Innes & Tikina, 2017). The concept is thus connected to planetary boundaries as these are used to determine the levels of disturbances that are within the safe range for the planet (Steffen et al., 2015).

Maintenance of functional biodiversity and redundancy can help to improve resilience and prevent forest ecosystems to tip into undesired states.

The collection of indicators to measure pressures and condition departs from the 2nd MAES report (Maes et al., 2014) and has been extended from different sources: 1) Input received from the MAES working group; 2) literature review based on e.g. the study of Lausch et al. (2016) on indicators of forest health, the review of Gao et al. (2015) on biodiversity indicators for forest ecosystems in Europe, and the study of Trumbore et al. (2015) on forest health and global change; 3) information from the European Topic Centre on Biological Diversity; 4) information on forest condition in Europe from the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests) (Michel & Seidling, 2015); 6) Indicators from the State of Europe's Forests report (FOREST EUROPE, 2015); 7) the report on Criteria and Indicators for Sustainable Forest Management in Europe from the European Forest Institute (2013), and 8) the report on state and trends of European forest ecosystems (European Environment Agency, 2016). Finally, the collection of indicators underwent several rounds of review (see chapter 3). Table 4.3 shows the indicators classified according different pressures and condition classes.

Pressure indicators of forest ecosystems were classified in seven high-level categories. Forest ecosystems are exposed to pressures as part of their natural evolution, natural pressures inside the range of normal background levels are important for several ecosystem processes. They contribute to a healthy mix of patches and to maintain water balance, biomass and diversity at landscape scale (Trumbore et al., 2015). Healthy, vigorous and resilient forest ecosystems can return to their initial condition following the occurrence of catastrophic events, e.g. fires or windstorms, within the "normal" boundary of occurrence, and any resulting change to its systemic nature. In consequence, after the recovery period, the capacity of providing ecosystem services is restored as well. Nevertheless, human-driven pressures such as over-exploitation, over-harvesting, climate change, air pollutants or invasive pests, might push the system to new states beyond the capacity of evolutionary adaptation, leading to forest decline and unhealthy forests.

The condition indicators cover structural, functional and compositional attributes of forest ecosystems. The indicators were classified in seven high-level categories. The first, environmental quality, reports abiotic attributes. Then ecosystem attributes are in structural attributes (general), structural attributes based on species diversity and abundance, structural attributes based on the EU nature directives, structural soil attributes, functional attributes (general) and functional soil attributes.

Important structural condition indicators are deadwood, forest fragmentation/connectivity, biomass volume and forest area. And forest tree species among others regarding the category structural based on species diversity and abundance. Within the category structural based on the EU nature directives, the share of forest covered by Natura 2000 or by Nationally Designated Area as well as indicators on common forest birds, and conservation status of forest habitats and species receive special attention.

The condition of forest soils can be assessed by several indicators on soil biodiversity, pH, soil organic carbon, soil moisture, compaction (bulk density) and erodibility (i.e., risk to be eroded).

Several functional indicators are part of the framework for forest ecosystems. Many of them are derived from remote sensing integrated with ground data for calibration and validation.

Table 4.3. Indicators for pressures and condition of forest ecosystems

Pressures	
Habitat conversion and degradation (land conversion)	**Fragmentation by roads and other linear features (index)**
	Fragmentation by forest cover loss (index)
	Forest cover change and deforestation (ha/year)
	Landslides (number/year, area/year)
	Soil sealing (ha/year)
Climate change	Forest damage by storms and/or other extreme weather events (damage: ha/year or timber m3/year)
	Change in climate parameters (including drought): long term changes (>=30-year) (e.g.: °C, mm, indexes)
	Number of fires (number/year)
	Burnt area (ha/year)
	Change in soil moisture (water stress) (index)
	Drought and heat induced tree mortality, drought stress (area/time unit)
Pollution and nutrient enrichment	**Formation of tropospheric ozone (ground level ozone) (ppb/year)**
	Deposition of nitrogen, sulphate, sulphur, calcium and magnesium (kg/ha/year)
	Excessive nutrient loading: Nitrogen in soil (kg/ha/year), C/N ratio in soil (ratio)
	Acidification (kg S/ha/year)
	Industrial (point) and diffuse soil pollution (heavy metals concentration) (mg/kg/year)
Over-exploitation	See note 1
Over-harvesting	**Long term ratio of annual fellings (m3/ha/year) to net annual increment (m3/ha/year) (SEBI 017) see note 2**
Introduction of invasive alien species	Number of annual introductions of invasive alien species* (number/year)
Other	Insect outbreaks, pest damage and parasites (damage: ha/year or timber m3/year)
	Damage by wildlife and herbivores (damage: ha/year or timber m3/year)
	Soil erosion (kg/ha/year)
Ecosystem condition	
Environmental quality	Percentage of forest designated as "protective forests" (soil, water, other functions and infrastructure and managed resources) (%)
	Percentage of forest under management plan or equivalent instruments (%)
	Tropospheric ozone (ground level ozone) concentration (ppb)
	Concentration of nitrogen, sulphate, sulphur, calcium and magnesium (kg/ha)
Ecosystem attributes	
Structural ecosystem attributes (general)	**Deadwood (m3/ha) (SEBI 018)**
	Plant functional types (typology)
	Forest types (typology)
	Forest age structure (% of forest in age categories)
	Seral diversity (typology)
	Defoliation (% of trees)
	Discolouration (% of trees)
	Tree height (m)
	Tree cover density (%)
	Tree crown size (diameter, m)
	Forest fragmentation and connectivity (index) (SEBI 013) (CI)
	Biomass volume (growing stock) (m3/ha) (SEBI 017)
	Carbon stock (tonne/ha)
	Forest area (km2)
	Forest structural heterogeneity (index from remote sensing)
	Forest structural homogeneity (index from remote sensing)
	Canopy volume (from remote sensing) (m3)
	Naturalness (index or typology)

	Invasive alien species (number or richness) (number of species/area unit)
	Leaf-related indicators (see note 3)
	Pigment content (chlorophyll, carotene xanthophyll) (µg/g)
	Content of: nitrogen, phosphorous, carbon, lignin, cellulose, phenole, plant water content, wax, starch, sugar (%)
Structural ecosystem attributes based on species diversity and abundance	Species diversity, richness (number and abundance of species, including vascular plants, vertebrates, etc.) (number of species, indexes)
	Phylogenetic diversity (index)
	Forest tree species (number of species or species richness), tree sp. composition (index)
	Genetic variability (index; % of forest managed for the conservation and utilization of forest tree genetic resources)
	Threatened forest species (red list index) (SEBI 002) (CI)
	Understory vegetation (species richness) (index)
	Rove and ground beetles (species richness) (index)
	Bryophyte, moss, liverwort, lichen and fungal species richness (index)
Structural ecosystem attributes monitored under the EU nature directives	**Percentage of forest covered by Natura 2000 (%)**
	Percentage of forest covered by Nationally Designated Areas (%)
	Threatened forests related habitats (Red List index) (%, number, area) (CI)
	Conservation status and trends of habitats of Community interest associated to forest (%) (SEBI 005)
	Abundance and distribution of common forest birds (index) (SEBI 001) (CI)
	Conservation status and trends of species of Community interest associated to forest (%)
	EU Population status and trends of bird species of Community interest associated to forest (%)
Structural soil attributes	Soil biodiversity (DNA-based richness and abundance)
	Soil pH (pH)
	Soil organic carbon (SOC) (% or g/kg)
	Soil moisture (water stress) (index)
	Bulk density (kg/m3)
	Soil erodibility (K-factor) (tonne ha h/MJ mm)
Functional ecosystem attributes (general)	Photosynthesis (e.g. indexes: NDVI (Normalized Difference Vegetation Index), VCI Copernicus (Vegetation Condition Index), fPAR (Fraction of Photosynthetically active radiation), LAI (Leaf Area Index)) (CI)
	Chlorophyll fluorescence (remote sensing proxies)
	Carbon sequestration (Dry matter productivity Copernicus) (tonne/ha/year)
	Plant productivity (NPP) (tonne/ha/year)
	Evapotranspiration (l/ha/day)
	Leaf respiration (net ecosystem–atmosphere CO2 exchange)
	Leaf phenology type, leaf age, leaf development (measures according to annual cycles)
	Plant and canopy phenology (measures according to annual cycles)
	Carbon dioxide exchange and carbon balance (net ecosystem–atmosphere CO2 exchange)
	Greening response (remote sensing proxies)
Functional soil attributes	Available water capacity (index)
	Nutrient availability (nitrogen and phosphorus) (mg/kg)

Table notes: [1]According to the EU Forest Strategy (COM(2013) 659 final) *sustainable forest management means using forests and forest land in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*. For the purpose of MAES the notion of 'over-exploitation' comprises all forest management practices with adverse effects on these objectives, and which can be assessed by an array of indicators embracing relevant aspects of forest condition and forestry practices.

[2] The indicator should be measured as long-term average (ideally taking into consideration information on annual fellings and net annual increment for the whole rotation period or more) and it should be interpreted carefully, taking into account complementary information and other indicators. For instance, large areas of older stands may have large potential for harvesting and relatively small mean net annual increments. Another example is the use of fast-growing non-native species or fertilisation which may contribute to an increase in growing stock, but may be detrimental to biodiversity (see: https://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings/forest-growing-stock-increment-and-4).

[3] Leaf-related indicators: size (mm), form (typology), type (typology), anatomy (typology), optical properties (reflectance measurements), wettability traits (g/m^2), dry matter content (%), specific leaf area (m^2/kg), mass per area (g/m^2), carbon content (%), nitrogen content (%), phosphorus content (%), pigment content (%), water content (%).
CI: Composite Indicator; Indicators printed **in bold** are key indicators (see also section 4.3.1); SEBI: Indicator of Streamlining European Biodiversity Indicators; *This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

One of the challenges when assessing forest condition is the spatial and temporal scale. A local infection is considered as a threat at local level but not important at landscape level. However, such an infection can develop into an epidemic and affect forests at the landscape scale. In another example, a single tree is considered healthy when there is absence of disease, but on a larger scale a forest stand can be healthy even though few individuals are unhealthy (Innes & Tikina, 2017; Kolb et al., 1994). Regarding the temporal scale, forest recovery after disturbance might take different periods depending on a number of factors such as species composition, forest age and management practices among others. Additionally, forest processes and functions recover at different periods. For instance, photosynthesis and respiration recover within a few years, biomass within a few decades, while mineral nutrients can take several decades to recover (Trumbore et al., 2015).

4.3.1 Key indicators

The indicators of Table 4.3 which are printed in bold are considered key indicators for pressures and condition of forest ecosystems. These indicators have at least two policy uses, and a baseline and time series data is available at European scale. Key indicators are already reported under other policy frameworks, nevertheless improvements are feasible exploiting, for example, available and future data from the Copernicus Programme[11]. For pressures, six indicators are part of the key indicators. Regarding condition 14 indicators were included in the key group.

4.3.2 Example of an application of the indicator framework in forest policy

Figure 4.3a shows a synthesis of the links between pressures, condition and ecosystems services in forest ecosystems. Additionally, the figure illustrates some examples of policy objectives. In forest ecosystems, structural, functional and compositional traits are highly interrelated. Therefore, changes in one attribute have an effect in other attributes, for instance changes in structure generally affects functions and compositional traits. The links in the figure are fundamental for translating the conceptual framework into applications. Several relations emerge between pressures and condition. Forest cover change and climate change affects a range of condition indicators. Similarly, over-harvesting affects the ratio between fellings to increment but also other indicators. We acknowledge that the links described are not necessarily exhaustive, and that the framework can be further developed using a higher level of refinement.

The provision of forest ecosystem services is strongly related with forest ecosystem condition. Many links are established between condition and services in a one-to-one and, more often, one-to-many relationship. For example, biomass volume is a key attribute of forest that is related to many ecosystem functions and thus also with the provision of ecosystem services.

[11] http://www.copernicus.eu/

Forest ecosystems play an important role in environmental and other policy objectives. The box on the right part of Figure 4.3a shows examples of policy objectives linked to services, condition and pressures. Figure 4.3b is an example showing the links for the policy objective of improving the condition of fragmented forests.

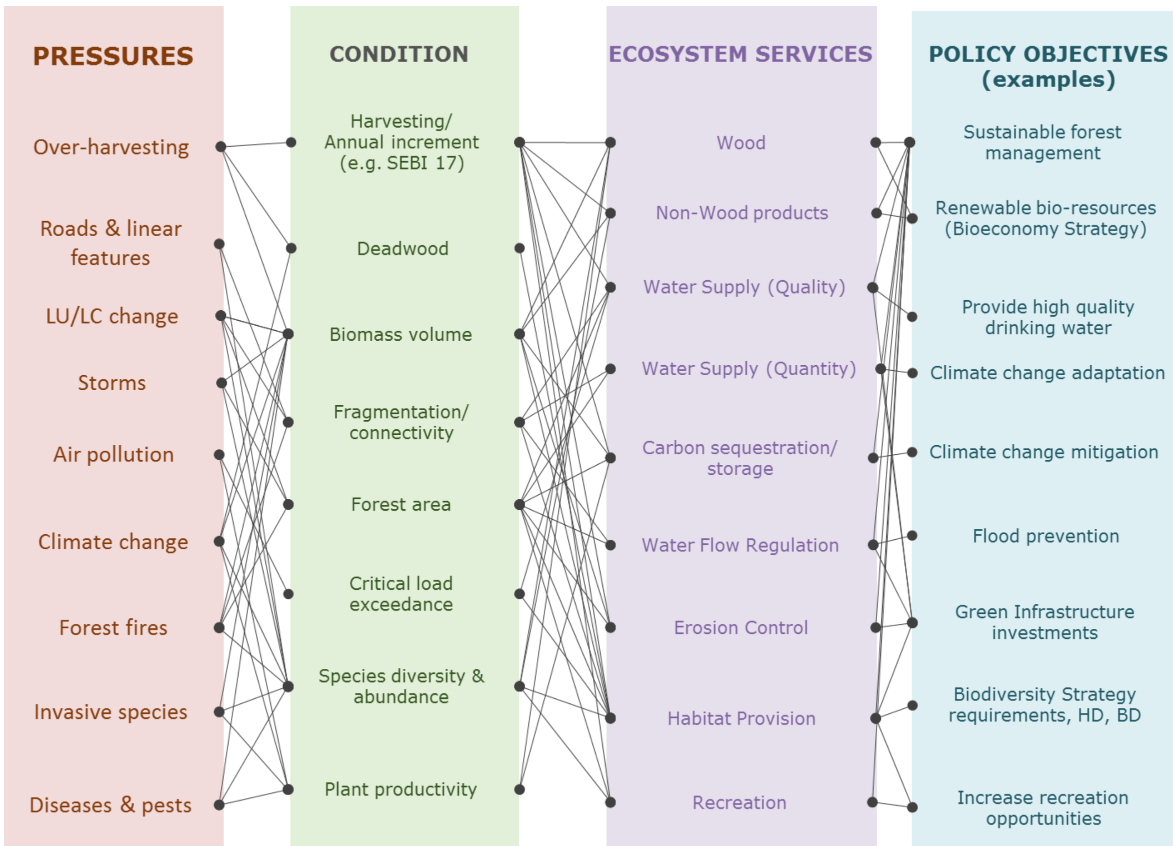

Figure 4.3a. Synthesis of the links between pressures, condition and ecosystem services in forest ecosystems

In the framework, forest pressures are approached from the affected forest attributes and processes interactions. In the example of forest fragmentation (from Carpenter et al., 2009) changes in one attribute can lead to effects in other attributes. For instance, roads and forest cover change in a forested landscape do not just affect connectivity and species richness and abundance, but also impacts hydrology and landscape nutrient cycles. In this case, fragmentation leads to changes in services such as water supply, water quality and erosion control independently of the effects on biodiversity, which can, in turn, influence other ecosystem services such as habitat provision. In the example, green infrastructure should be oriented to restore forest connectivity at landscape level and improve forest condition through nature-based solutions, specifically addressing those condition features affected by fragmentation. The example is useful for describing the complex non-linear effects of pressures on forest ecosystem services. It is rare to find a linear cause-effect path from changes in pressures, condition and ecosystem services. On the contrary, cause-effect processes are complex in most cases.

The example illustrates potential uses of the indicator framework including (1) assessing policy options in degraded ecosystems by linking policy options with ecosystem services, forest condition and the causal pressures; (2) identifying using a territorial approach, i.e. with spatially-explicit indicators, degraded areas of forest (in poor condition) and where and how restoration options can be implemented; (3) facilitating the integration of different policy streams regarding forest ecosystems within an ecosystem-based approach.

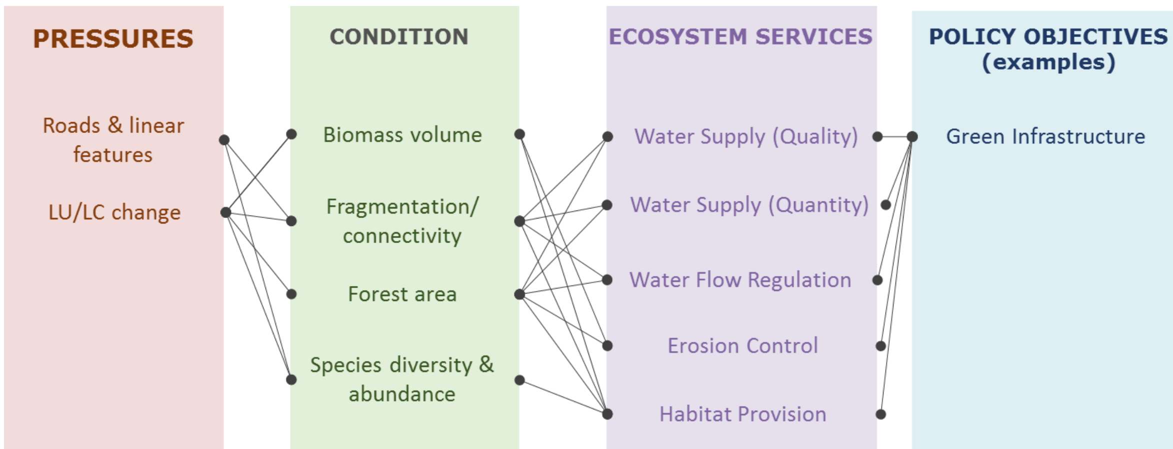

Figure 4.3b. Extraction of the nodes and links of Figure 4.3a to illustrate the example of mitigating the impact of forest fragmentation.

4.4 Heathland and shrub, sparsely vegetated land and wetlands

This section focusses on ecosystems which are to a large extent covered by the Habitats Directive (HD) and the Birds Directive (BD), the so-called Nature Directives because of their high values for biodiversity. Following the MAES typology, these ecosystems are 'Heathland and shrubs', 'Sparsely vegetated land', and 'Wetlands'.

Heathland and shrubs are dominated by woody shrubs often in combination with herbs, and sometimes with a large contingent of mosses, liverworts and lichens. They are distributed across all the biogeographic regions of Europe from the lowlands to the uplands. Most of these habitats are strongly dependent on human interventions, particularly grazing and fire. With a specific relationship with traditional pastoral systems they occupy an intermediate position between more intensively managed grassland types and mature woodlands.

Sparsely vegetated lands include bare or sparsely vegetated rock, lava, ice and snow of cliffs, screes, caves, volcanoes, glaciers and snow-fields, dunes, beaches and sand plains. They occur throughout Europe and they are shaped by geological or climatological processes.

Wetlands include mires, bogs and fens and are considered as terrestrial ecosystems dominated by herbaceous or heather vegetation with the water table at or above ground level for at least half of the year. They don't include surface water bodies which are represented by the ecosystem type "rivers and lakes" nor estuarine and coastal wetlands which are classified under the ecosystem type "Marine inlets and transitional waters".

Ecosystems are sensitive to several types of pressures and their conditions could be evaluated by different parameters. In Table 4.4 the description of the pressures and condition indicators is limited to the availability of existing information at EU level. However, in a different context and conditional on the available information at regional, national or local levels, other indicators can be described and used.

The conversion of heathlands to artificial land uses or resulting from land abandonment is an important pressure. Land abandonment results in the extension of forest linked with the loss of the heathland specific biodiversity.

For sparsely vegetated lands, mining and quarrying lead to a reduction of surface area. Both ecosystem types are affected by the exceedance of nitrogen which impacts species diversity. Due to the high importance of the water balance for their functioning, wetlands are very sensitive to climate change, pollution by eutrophication and agricultural intensification.

The evaluation of the condition of these ecosystems can be estimated using the level of fragmentation, the level of protection at EU and national levels, the status of conservation as measured by IUCN category for all habitats of these ecosystems. Additionally, their conservation status as evaluated under the Nature directives is available for a selection of habitats and species associated to these ecosystems.

Table 4.4. Indicators for pressures and condition of heathland and shrub, sparsely vegetated land and wetlands.

Pressures		
	Heathland and shrub	**Sparsely vegetated land**
Habitat conversion and degradation (Land conversion)	**Change of area due to conversion (%/year) (SEBI 004)**	
	Landscape abandonment (CI)	
	Change in forest extent (CI)	
Climate change	n.a.	
Pollution and nutrient enrichment	**Critical load exceedance for nitrogen (eq/ha/y) (SEBI 009)**	
Over-exploitation	n.a.	
Introductions of invasive alien species	Number of annual introductions of invasive alien species* (number/year)	
Other	Soil erosion (tonne/ha/year) (AEI21)	
	Soil sealing (ha/year)	
Ecosystem condition (heathland and shrub, sparsely vegetated land)		
Environmental quality	n.a.	
Ecosystem attributes		
Structural ecosystem attributes (general)	**Landscape fragmentation (CI)**	
	Threatened heathlands (or) sparsely vegetated land related habitats (%, number, area)	
Structural ecosystem attributes based on species diversity	n.a.	
Structural ecosystem attributes monitored under the EU Nature directives	**Conservation status & trends of habitats of Community interest associated to heathlands (or) sparsely vegetated land (%)**	
	Conservation status & trends of species of Community interest associated to heathlands (or) sparsely vegetated land (%)	
	EU Population status & trends of bird species associated to heathlands (or) sparsely vegetated land (%)	
	Percentage of heathlands (or) sparsely vegetated land covered by Natura 2000 (%)	
	Percentage of heathlands (or) sparsely vegetated land covered by Nationally Designated	

	Areas (%)
Structural Soil attributes	Soil biodiversity (DNA-based richness and abundance)
	Soil organic carbon (SOC) (% or g/kg)
	Soil erodibility [K-factor (tonne ha h/MJ mm)]
Functional ecosystem attributes (general)	n.a.
Functional soil attributes	Available water capacity (index)
	Soil nutrients availability (nitrogen & phosphorus) (mg/kg)

Pressures (Wetlands)	
Habitat conversion and degradation (Land conversion)	**Change of area due to conversion (%/year) (SEBI 004)**
Climate change	Climate impact & sensitivity (CI)
Pollution and nutrient enrichment	Exposure to eutrophication (mol nitrogen eq/ha/y)
Over-exploitation	Agriculture intensity pressure on wetlands (CI)
Introductions of invasive alien species	Number of annual introductions of invasive alien species* (number/year)
Other	Soil erosion (tonne/ha/year) (AEI21)
	Soil sealing (ha/year)
	Loss of organic matter (%SOC/year)
Ecosystem condition (Wetlands)	
Environmental quality	n.a.
Ecosystem attributes	
Structural ecosystem attributes (general)	**Landscape fragmentation (CI)**
	Wetland connectivity indicator (< 10 km from other wetland / > 10 km from other wetland)
	Threatened wetlands related habitats (%, number, area)
Structural ecosystem attributes based on species diversity	Living Planet Index for Mediterranean wetlands (CI)
	Number & abundance of wetland bird species (number/ha)
	Community Specialisation Index (CI)
	Status of globally-threatened wetland-dependent birds/amphibians
Structural ecosystem attributes monitored under the EU Nature directives	**Conservation status & trends of habitats of Community interest associated to wetlands (%)**
	Conservation status & trends of species of Community interest associated to wetlands (%)
	EU Population status & trends of bird species associated to wetlands (%)
	Percentage of wetlands covered by Natura 2000 (%)
	Percentage of wetlands covered by Nationally Designated Areas (%)
Structural soil attributes	Soil biodiversity (DNA-based richness and abundance)
	Soil organic carbon (SOC) (% or g/kg)
	Bulk density (kg/m3)
	Soil moisture (%)
Functional ecosystem attributes (general)	n.a.
Functional soil attributes	Available water capacity (index)

Table notes: Indicators in printed in bold are key indicators; n.a.: not available or not applicable; SEBI: Indicator of Streamlining European Biodiversity Indicators; AEI: Agri-Environment Indicator; *This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

4.4.1 Key indicators

In Table 4.4 indicators in bold are considered as key indicators with at least two policy uses and for which a baseline and time series of data are available at European scale.

4.4.2 Example of an application of the indicator framework in policy

Even though the three ecosystems described in this section have a number of common links between pressures, condition and ecosystem services as shown in Figure 4.4, it is important to understand their own specificities.

Heathlands and shrubs have a strong relationship with traditional pastoral systems, being often grazed by sheep and goats, constituting an important resource for herding. The abandonment of such practices has triggered change towards forests in many areas and a reduction of shrubs. Climate change and human disturbances can alter the fire regime of this ecosystem especially in the Mediterranean area, which influences biomass and functional characteristics. Recurrent fires and land conversion negatively affects the ecosystem's carbon uptake and storage, and the burnt and regenerating habitats have reduced capacities for flood control and erosion control.

Wetlands have also important functions with peat sequestering carbon but they act as water reservoirs and buffer discharge as well. Part of a natural catchment they function as sponges which prevent lower parts of the catchment from flooding in periods of heavy rain, and still provide water for a long time in periods of drought. Renewal of freshwater fish stocks can also benefit from a better water quality as well as nutriments for fish nurseries and reproduction.

Any concrete action aiming to protect, improve or restore wetlands will support a nature-based solution for improving the regulation of water quality and quantity. Then a communication on this action with an access and use as recreation area can also bring attention and support from the public towards biodiversity policy targets.

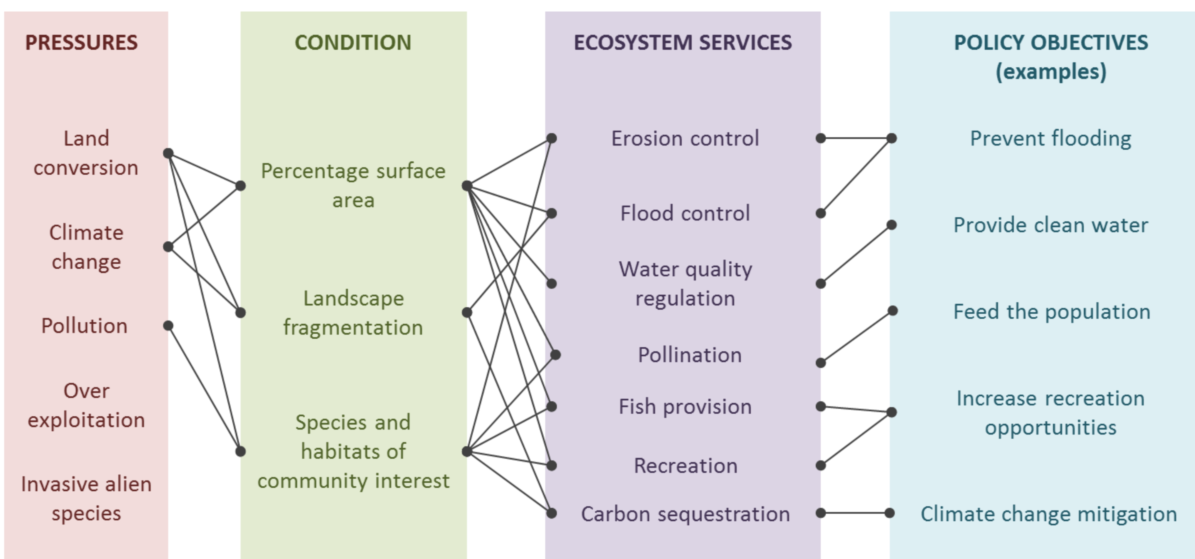

Figure 4.4. Synthesis of the links between pressures, condition and ecosystem services in heathland and shrub, sparsely vegetated land and wetlands

4.5 Freshwater ecosystems

Freshwater ecosystems include rivers, lakes and groundwater. Their condition and functioning is tightly connected to natural ecosystems at the water-land interface, such as riparian areas, floodplains and wetlands. This section focuses on rivers, lakes and groundwater, while wetlands are discussed in section 4.4 and transitional and coastal waters in section 4.6.

The definition of ecological status provided by the Water Framework Directive (WFD, Directive 2000/60/EC) can be adopted to describe the condition of freshwater ecosystems. According to the WFD the ecological status "is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters".

The collection of indicators for measuring pressures and condition in freshwater ecosystems (Table 4.5) is based on the MAES Freshwater pilot and recent studies (Maes et al., 2014, Maes et al., 2016; Grizzetti et al., 2016; 2017; Pistocchi et al., 2015; 2017), and has been discussed in the MAES condition workshop of 27-28 June 2017[12].

Indicators of pressures on freshwater ecosystems include: 1) water abstractions and the presence of reservoirs; 2) waste water discharges from waste water treatment plants (WWTPs), urban areas and industries, diffuse pollution from agriculture (nutrients and pesticides) and atmospheric deposition; 3) overfishing and the introduction of alien species; and 4) the loss of habitat due to channelization (changes in hydromorphology) or conversion from natural to artificial areas in floodplains or riparian areas (Table 4.5).

Indicators of condition of freshwater ecosystems (Table 4.5), reflecting the presence of pressures, are related to: 1) the alterations of water quantity and seasonality (for example the alteration of water environmental flow); 2) the concentration of pollutants in water, such as nutrients, feacal bacteria, metals; 3) the presence of alien species; 4) the existence of barriers and reservoirs, and the fraction of soil sealed in the drained area or in the connected floodplain.

Water abstractions and fish catches affect ecosystem conditions when they are above sustainable thresholds. However, while for water quantity indicators such as the Water Exploitation Index can inform on the relative consumption of water compared to the total available quantity, no such indicators exist for fish catches, for which information on the total available stock is generally not available.

The ecological status established by the WFD is an integrated measure of the structure and functioning of freshwater ecosystems. It is quantified per single water body using biological assessment methods that consider biological quality elements (BQEs, i.e. phytoplankton, flora, invertebrate fauna and fish fauna), and information on physico-chemical and hydromorphological conditions. It is expressed in five classes: high, good, moderate, poor and bad. A water body is in good condition if it is classified as having at least good ecological status[13]. The ecological status is quantified by each Member State through national assessment methods. The methods were intercalibrated, to assure the coherence of the classification across EU countries.

[12] A background document is available on CIRCA BC (see also chapter 3)

[13] The Water Framework Directive indicates that: "*Good surface water status means the status achieved by a surface water body when both its ecological status and its chemical status are at least good*", and "*Good groundwater status means the status achieved by a groundwater body when both its quantitative status and its chemical status are at least good*".

For the assessment of the ecological status of water bodies Member States collect also specific data on the biological quality elements (BQEs): 1) composition, abundance and biomass of phytoplankton, 2) composition and abundance of other aquatic flora, 3) composition and abundance of benthic invertebrate fauna, 4) composition, abundance and age structure of fish fauna. These indicators can be used to describe the biodiversity of the freshwater ecosystems. An additional indicator of condition can be the presence and trends of invasive alien species of concern. This information will be collected and reported by Member States under the EU Regulation (1143/2014) on Invasive Alien Species.

Several indicators of structural ecosystem attributes are monitored under the EU Nature Directives, such as the proportion of freshwater covered by Natura 2000, the conservation status and trends of habitats and species of Community interest associated to rivers and lakes, and population status and trends of bird species of Community interest associated to rivers and lakes. Finally, indicators such as water flow and chlorophyll concentration can be considered as indicators of functional ecosystem attributes for rivers and lakes, respectively.

Only some of the indicators described in Table 4.5 are relevant for groundwater: fertilizer inputs, gross nutrient balance and water abstractions (from aquifers) as indicators of pressures; and the chemical and quantitative status of groundwater as indicators of condition.

The spatial scale of assessment of pressure and condition indicators presents some challenges for freshwater ecosystems. In fact, while rivers and lakes can be mapped, water dynamically flows through the water cycle in the river basin, involving soils, groundwater, rivers, lakes, wetlands, riparian areas and coastal waters. Therefore, in addition to the water body, another relevant spatial scale for freshwater ecosystems is the river basin (or the sub-basin), which identifies the area where the freshwater ecosystems are interconnected. However, it is worth noticing that spatial data on pressures are generally available by administrative units (at national or regional level), and their allocation per river basin or water body might be challenging.

Table 4.5. Indicators for pressures and condition of freshwater ecosystems

Pressures	
Habitat conversion and degradation (Land conversion)	**Land take (ha/year) (conversion from natural to artificial areas in floodplains or riparian areas)**
	Ecosystem coverage change (%/year) (related to SEBI 004)
Climate change	Change in water temperature (°C/year)
Pollution and nutrient enrichment	**Critical load exceedance for nitrogen (eq/ha/year) (SEBI 009)**
	Nitrogen and phosphorus fertilisers use in the basin (kg/ha/year);
	Gross nutrient balance (kgN/ha/year; kgP/ha/year) (SEBI 019)
	Consumption of pesticides (tonne/year)
	Waste water collection and treatment rate (%); or discharge of urban waste water (tonne N/year; tonne P/year)
Over-exploitation	Water abstractions (total or by sector) (m3/year)
	Fish catch (tonne/year)*
Introductions of invasive alien species	**Number of annual introductions of invasive alien species (number/year)**
Ecosystem condition	
Environmental quality	Chemical status (water) (CI)
	Nitrogen concentration (mgN/l), phosphorus concentration (mgP/l), BOD (mg/l) (SEBI 016)
	Organic pollutants, metals, pesticides concentration
	Bathing water quality (quality levels)
	Flow alteration (%) (ex. days the environmental flow is not respected in a year)
	Water Exploitation Index (%)
	Land cover in the drained area or floodplain (%) (ex. natural areas in floodplains; density of infrastructures in floodplains; artificial land cover or soil sealing in floodplains; agricultural land cover in floodplains; ecosystem coverage)
	Density of dams in the drained area (number/km2)**
Ecosystem attributes	
Structural ecosystem attributes (general)	**Ecological Status (CI)**
Structural ecosystem attributes based on species diversity and abundance	Biological quality elements (BQEs) collected to assess ecological status (ex. composition and abundance of aquatic flora, benthic invertebrate fauna, fish fauna, phytoplankton)
	Presence of alien species reported under the EU Regulation (1143/2014) (number)
Structural ecosystem attributes monitored under the EU nature directives	**Proportion of freshwater covered by Natura 2000 (%)**
	Proportion of freshwater covered by Nationally Designated Areas (%)
	Threatened freshwater related habitats (%, number, area)
	Conservation status and trends of habitats of Community interest associated to rivers & lakes (%)
	Conservation status and trends of species of Community interest associated to rivers & lakes (%)
	EU population status and trends of bird species associated to rivers & lakes (%) (CI)
Functional ecosystem attributes	Water flow (m3/s)
	Chlorophyll fluorescence (concentration, from remote sensing proxies)

Table notes: *A better indicator to quantify fish over-exploitation would be fishing mortality in comparison to its maximum sustainable yield. However, data on fish mortality at maximum sustainable yield for freshwater fisheries are hardly available. Fish catches is proposed as a proxy because of the lack of data; **); River fragmentation (SEBI 014 - not developed yet); Indicators printed **in bold** are key indicators (see also section 4.5.1); Indicators in red are indicators which at present are difficult to quantify at European scale due to a lack of consistent and harmonised data; **CI**: Composite Indicator; SEBI: Indicator of Streamlining European Biodiversity Indicators.

4.5.1 Key indicators

Some of the indicators reported in Table 4.5 are proposed as key indicators for pressures and condition of freshwater ecosystems and highlighted in bold. These are the indicators with at least two policy uses and for which a baseline and time series of data is available at European scale. Proposed key indicators for pressures are: land take, ecosystem coverage change, critical load exceedance for nitrogen, gross nutrient balance and the introductions of invasive alien species. Proposed key indicators for condition are: freshwater quality; Water Exploitation Index; land cover in the drained area or floodplain, Ecological Status (WFD); proportion of freshwater covered by Natura 2000; conservation status and trends of habitats and species of Community interest associated to rivers and lakes (Nature Directives).

The Ecological Status should be considered the most representative and homogeneous indicator across Europe, but missing information in the data reported under the first and second cycle of implementation of the WFD might hamper the use of this information for trend analysis. In addition the ecological status is reported only every 6 years.

4.5.2 Example of an application of the indicator framework in policy

Pressures acting on freshwater ecosystems, relative changes in ecosystem condition, associated delivery of ecosystem services and relationships with policy objectives are all interconnected. Figure 4.5a describes in a non-exhaustive way these possible links.

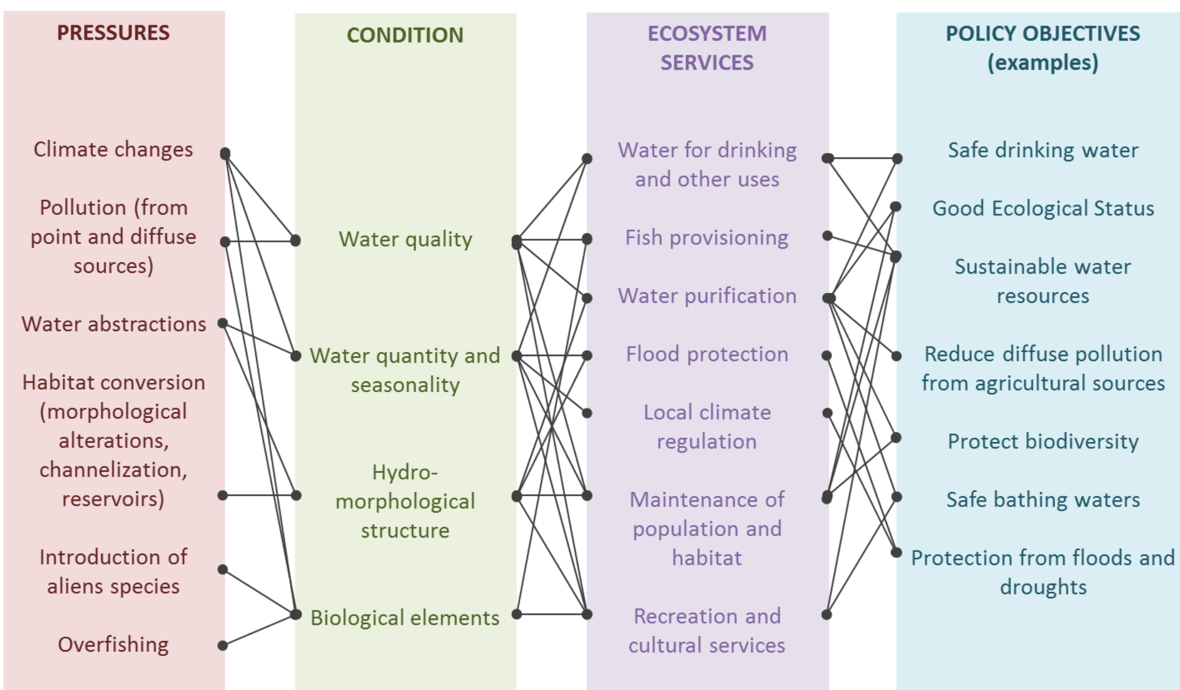

Figure 4.5a. Links between pressures, condition and ecosystem services in freshwater ecosystems (adapted from Grizzetti et al., 2016). The links are not exhaustive.

For example (Figure 4.5b), nutrient pollution from agriculture and point sources, such as industrial or urban waste water discharges, affect the water quality of rivers, lakes and groundwater. Several ecosystem services depend on water quality. Indeed almost all water uses require meeting quality standards, otherwise water is treated before use, with associated costs. In particular, stringent water quality requirements are to be respected for drinking water, regarding microbiological and chemical parameters. The quality of water also directly affects fish growth and the associated quality and quantity of fish stock (fish provisioning). In addition, the removal of contaminants is less efficient in polluted water ecosystems (water purification). For instance the efficiency of nitrogen removal decreases when the concentration of nitrogen is too high. Finally, recreational activities depend on water quality, e.g. bathing is possible only if waters meet sufficient quality standards, otherwise posing a concrete risk to human health.

The example suggests that good water ecosystem condition, in this case measured by water quality, can support multiple services for people. These services are the focus of several objectives of EU policies, including: provide safe drinking water (Drinking Water Directive[14]); protect or promote Good Ecological Status in all freshwater ecosystems (WFD); ensure sustainable use of water resources (WFD); reduce diffuse pollution from agricultural sources (Nitrates Directive); protect biodiversity (Biodiversity Strategy); ensure safe bathing waters (Bathing Water Directive[15]).

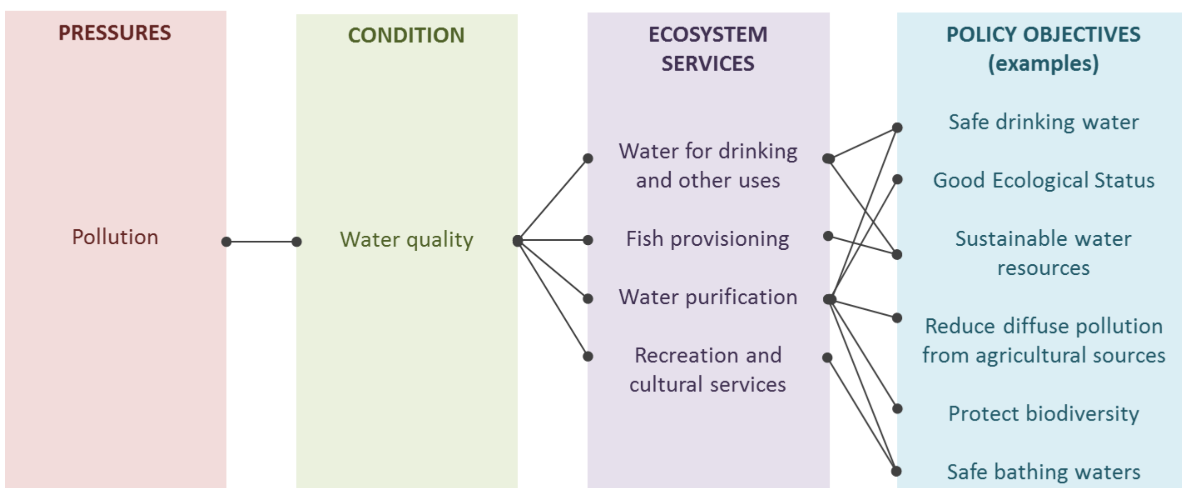

Figure 4.5b. Extraction of the nodes and links of Figure 4.5a to illustrate the example of clean water for different uses.

[14] Council Directive 98/83/EC
[15] Directive 2006/7/EC of the European Parliament and of the Council

4.6 Marine ecosystems

This section focusses on marine ecosystems, defined as encompassing all marine waters, including waters at the land/sea interface with salinity higher than 0.5‰. Following the MAES typology, four ecosystems are considered: marine inlets and transitional waters, coastal waters, shelf waters, and open ocean.

The definition of environmental status provided by the Marine Strategy Framework Directive (MSFD) can be adopted to describe the condition of marine ecosystems. According to the MSFD the environmental status means the overall state of the environment in marine waters, taking into account the structure, function and processes of the constituent marine ecosystems together with natural, physiographic, geographic, biological, geological and climatic factors, as well as physical, acoustic and chemical conditions, including those resulting from human activities inside or outside the area concerned.

4.6.1 Marine inlets and transitional waters and coastal waters

Marine inlets and transitional waters are ecosystems on the land water interface with a salinity higher than 0.5‰ and under tidal influence. They include coastal wetlands, lagoons, estuaries, fjords, sea lochs and marine embayments. The coastal waters are shallow, marine systems subject to significant land-based influences.

Importantly, marine inlets and transitional waters as well as coastal waters fall mainly under the provisions of the Water Framework Directive up till one nautical mile in seaward direction. The Marine Strategy Directive covers coastal waters beyond one nautical mile or comes into play for those aspects not covered by the WFD.

The set of indicators selected for assessing pressures and condition of transitional and coastal water ecosystems is presented in Table 4.6. Indicators of pressures include:

- natural seabed loss rate (benthic habitat) as a result of bottom trawling or mining activities;
- rates of acidification, temperature increase and sea level rise, mainly as a consequence of climate change;
- nutrient and contaminants release (from river discharge, point- and diffuse coastal sources, as well as from aquaculture);
- overfishing and introduction of alien species (the latter as a consequence, inter alia, of aquaculture activities).

Water pollution and fishing activities (including bottom trawling) above sustainable thresholds affect ecosystem condition. Indicators of condition include chemical and ecological status, as the abiotic and biotic pillars of water quality in the WFD, but also:

- bathing water quality, chlorophyll-a concentration (in relation to nutrient concentration) and concentration of contaminant in seafood;
- concentrations of macro- and micro-litter, as well as underwater noise;
- conservation status, as well as extent of adverse effects on- or loss of- benthic habitats;
- conservation status of species (including birds) of Community interest;
- commercial fish stock status;

- presence of invasive alien species, and their effect on species group or habitats

The WFD states that "Good surface water status means the status achieved by a surface water body when both its ecological status and its chemical status are at least good." Thus, Member States assess good water status through national assessment methods, intercalibrated to assure coherence of water status classification across the EU. The assessments rely on the collection of specific data on the physico-chemical and biological quality elements.

The MSFD aims at achieving a "good environmental status" (GES) for all EU seas by 2020. GES is defined through a set of 11 Descriptors. To ensure consistency and to allow for comparison between marine regions or sub-regions as to the extent to which GES is being achieved, a set of criteria and methodological standards is set forth for each descriptor in the recently adopted COM DEC 2017/848/EU (repealing COM DEC 2010/477/EU). Thus, elements from COM DEC 2017/848/EU can complement the assessment of ecosystem condition. Additional elements of assessment of ecosystem condition can be derived also from the information collected and reported by Member States under the Habitats and Birds Directives, as well as the Common Fisheries Policy and the Invasive Alien Species Regulation.

Table 4.6. Indicators for pressures and condition of marine inlets and transitional waters and coastal ecosystems

Pressures	
Habitat conversion and degradation	Extent of loss of habitat (MSFD-D6C4) (%/year or km2/year)
Climate change	**Acidification (rate; per year)**
	Temperature increase (°C/year)
	Sea level rise (cm/year)
Pollution and nutrient enrichment	**Contaminants (WFD/MSFD-D9) (tonne/year)**
	Nutrient discharge (WFD) (N, P, tonne/year)
	Nutrient release from aquaculture (SEBI 022) (% increase/year)
Over-exploitation	**Fish catch (tonne/year)**
	Fish mortality of commercially exploited fish and shellfish exceeding Fmsy (fishing mortality at maximum sustainable yield) (MSFD-D3C1) (rate)
Introductions of invasive alien species	**Number of annual introductions of invasive alien species* (number/year) (MSFD-D2C1)**
	Number of newly introduced non-indigenous species from aquaculture (number/year)
Ecosystem condition	
Environmental quality	**Chemical Status (WFD) (CI)**
	Oxidized N, Orthophosphate, Nitrogen, Phosphorus, BOD (mg/l)
	Chlorophyll-a concentration (MSFD-D5C2) (mg/m3)
	Dissolved oxygen at the bottom of the water column (MSFD-D5C5) (mg/l)
	Bathing water quality (quality levels)
	Contaminants concentration in seafood (MSFD-D9C1) (mg/kg)
	Composition, amount and spatial distribution of litter (MSFD-D10C1) (number of items/m or /km2)
	Composition, amount and spatial distribution of micro-litter (MSFD-D10C2) (g/m2 or g/kg of sediment)

	Spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources (MSFD-D11C1) (km2)
	Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound (MSFD-D11C2) (km2)
Ecosystem attributes	
Structural ecosystem attributes (general)	**Ecological status (WFD)**
	Spatial extent and distribution of physical loss/disturbance to seabed (MSFD-D6C1 and D6C2) (km2)
	Spatial extent of adversely affected benthic habitat (MSFD-D6C3) (km2)
	Extent of loss of benthic habitat type (MSFD-D6C4) (km2)
	Extent of adverse effect on benthic habitat type (MSFD-D6C5) (km2)
	Habitat extent and condition (MSFD-D1C5) (km2)
Structural ecosystem attributes based on species diversity and abundance	**Population abundance (MSFD D1C2) (number of individuals/species or tonne/species)**
	Abundance and spatial distribution of established non-indigenous species, particularly of invasive species, contributing significantly to adverse effects on particular species groups or broad habitat types (MSFD-D2C2) (number of individuals or tonne or km2 per species)
	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to non-indigenous species, particularly invasive non-indigenous species (MSFD-D2C3) (ratio or km2)
	Spawning Stock Biomass (MSFD-D3C2) (tonne)
	Age and size distribution of commercially-exploited species (MSFD-D3C3) (% or number or cm)
	Biological quality elements (BQEs) collected to assess ecological status (ex. composition and abundance of aquatic flora, benthic invertebrate fauna, fish fauna, phytoplankton)
	Presence of invasive alien species reported under the EU Regulation (IAS 1143/2014)
Structural ecosystem attributes monitored under the EU nature directives	**Natura 2000 and Marine protected areas (% surface area)**
	Population status and trends of bird species of Community interest associated to transitional and coastal waters (%) (CI)
	Conservation status and trends of habitats of Community interest associated to transitional and coastal waters (%) (CI)
	Conservation status and trends of species of Community interest associated to transitional and coastal waters (%) (CI)

Table notes: Indicators printed **in bold** are key indicators (see also section 4.6.3); **CI**: Composite Indicator; SEBI: Indicator of Streamlining European Biodiversity Indicators; *The descriptor used in the frame of the MSFD is Number of newly introduced non-indigenous species but for the purpose of consistency with other ecosystem types a common terminology is used in this report.

4.6.2 Shelf and ocean waters

These ecosystems fall entirely under the provisions of the MSFD. The set of indicators selected for assessing pressures and condition of shelf and ocean water ecosystem is presented in Table 4.7. Indicators of pressures include:

- natural seabed loss rate (benthic habitat) as a result of bottom trawling or mining activities;
- rates of acidification, temperature increase and sea level rise, mainly as a consequence of climate change;
- nutrient and contaminants release (from point sources, including aquaculture);

- overfishing and introduction of alien species (the latter as a consequence, inter alia, of aquaculture activities).

Abiotic indicators of ecosystem condition include:

- concentration of nutrients and contaminants; concentration of contaminant in seafood is also considered, as well as chlorophyll-a concentration, used as a proxy for nutrient concentration;
- concentrations of macro- and micro-litter, as well as underwater noise;

while biotic indicators include:

- conservation status, as well as extent of adverse effects on- or loss of- benthic habitats;
- conservation status of species (including birds) of Community interest;
- commercial fish stock status;
- presence of invasive alien species, and their effect on species group or habitats;

Most of these indicators derive from MSFD with recently adopted COM DEC 2017/848/EU. The indicators on commercially exploited fisheries have a link to indicators of the Common Fisheries Policy (CFP). Elements from the Habitats (Directive 92/43/EEC) and Birds (Directive 2009/147/EC) Directives, as well as the Invasive Alien Species Regulation (EU Regulation 1143/2014) complement the assessment.

Table 4.7. Indicators for pressures and condition of shelf and ocean ecosystems

Pressures	
Habitat conversion and degradation	Extent of loss of habitat (MSFD-D6C4) (%/year or km2/year)
Climate change	**Acidification (rate)**
	Temperature increase (°C/year)
	Sea level rise (cm/year)
Pollution and nutrient enrichment	**Contaminants (MSFD-D9) (tonne/year)**
	Nutrient release from aquaculture (SEBI 22) (% increase/year)
Over-exploitation	**Fish catch (tonne/year)**
	Fish mortality of commercially exploited fish and shellfish exceeding Fmsy (fishing mortality at maximum sustainable yield) (MSFD-D3C1) (rate)
Introductions of invasive alien species	**Number of annual introductions of invasive alien species* (number/year) (MSFD-D2C1)**
	Number of newly introduced non-indigenous species from aquaculture (number/year)
Condition	
Environmental quality	**Oxidized N, Orthophosphate, Nitrogen, Phosphorus, BOD (mg/l)**
	Chlorophyll-a concentration (MSFD-D5C2) (mg/m2)
	Dissolved oxygen at the bottom of the water column (MSFD-D5C5) (mg/l)
	Contaminants concentration in water and sediments (MSFD-D8C1) (μg/l or μg/kg)
	Contaminants concentration in seafood (MSFD-D9C1) (mg/kg)
	Composition, amount and spatial distribution of litter (MSFD-D10C1) (number of items/m or /km2)

	Composition, amount and spatial distribution of micro-litter (MSFD-D10C2) (g/m2 or g/kg of sediment)
	Spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources (MSFD-D11C1) (km2)
	Spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound (MSFD-D11C2) (km2)
Ecosystem attributes	
Structural ecosystem attributes (general)	Spatial extent and distribution of physical loss/disturbance to seabed (MSFD-D6C1 and D6C2) (km2)
	Spatial extent of adversely affected benthic habitat (MSFD-D6C3) (km2)
	Extent of loss of benthic habitat type (MSFD-D6C4) (km2)
	Extent of adverse effect on benthic habitat type (MSFD-D6C5) (km2)
	Habitat extent and condition (MSFD-D1C5) (km2)
Structural ecosystem attributes based on species diversity and abundance	**Population abundance (MSFD D1C2) (number of individuals/species or tonne/species)**
	Abundance and spatial distribution of established non-indigenous species, particularly of invasive species, contributing significantly to adverse effects on particular species groups or broad habitat types (MSFD-D2C2) (number of individuals or tonne or km2 per species)
	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to non-indigenous species, particularly invasive non-indigenous species (MSFD-D2C3) (ratio or km^2)
	Spawning Stock Biomass (MSFD-D3C2) (tonne)
	Age and size distribution of commercially-exploited species (MSFD-D3C3) (% or number or cm)
	Presence of invasive alien species reported under the EU Regulation (IAS 1143/2014)
Structural ecosystem attributes monitored under the EU nature directives	**Marine protected areas (% surface area)**
	Population status and trends of bird species of Community interest associated to transitional and coastal waters (%) (CI)
	Conservation status and trends of species of Community interest associated to transitional and coastal waters (%) (CI)
	Conservation status and trends of habitats of Community interest associated to transitional and coastal waters (%) (CI)

Table notes: Indicators printed **in bold** are key indicators (see also section 4.6.3); **CI**: composite indicator; SEBI: Indicator of Streamlining European Biodiversity Indicators; *The descriptor used in the frame of the MSFD is Number of newly introduced non-indigenous species but for the purpose of consistency with other ecosystem types a common terminology is used in this report.

4.6.3 Key indicators

Key indicators for pressures and condition of marine ecosystems are defined as those with at least two policy uses and for which a baseline and time series of data is available at European scale. Many of the indicators proposed in Tables 4.6 and 4.7 come either from the WFD or from the MSFD.

The WFD is implemented in 6-year cycles, and is currently in its 2nd cycle of implementation. At each cycle Member States develop a River Basin Management Plan reporting, inter alia, on the chemical and ecological status of all water bodies in their territory, including transitional and coastal waters. Water status is quantified by each Member State through national assessment methods. The methods were intercalibrated, to assure the coherence of the classification across EU countries. Thus, indicators under the WFD are supported by harmonized time series at European scale.

The MSFD is also implemented in 6-year cycles. To ensure consistency and to allow for comparison between marine regions or sub-regions as to what extent good environmental status is being achieved, a commission decision (COM DEC 2010/477/EU replaced by COM DEC 2017/848/EU) defines the different descriptors and methodological standards the GES of marine waters. The second cycle of implementation will start in 2018, with reporting under Art 8 (assessment of marine waters) due by the end of that year. Thus, there is no availability of time series at EU scale yet.

Proposed key indicators are highlighted in bold in Tables 4.6 and 4.7. In relation to pressure, key indicators for all ecosystems are those related to climate change, water pollution, introductions of IAS and fishing activities (MSFD and CFP). Proposed key indicators for condition in transitional and coastal waters are: chemical and ecological status (WFD); water quality and bathing water quality (Bathing Water Directive); proportion of freshwater covered by Natura 2000; population abundance, spawning stock biomass, age and size distribution of commercially-exploited species (MSFD and CFP); conservation status and trends of habitats and species including birds, of Community interest associated to transitional and coastal waters.

4.6.4 Example of an application of the indicator framework in policy

Pressures acting on marine ecosystems, relative changes in ecosystem condition, associated delivery of ecosystem services and relationships with policy objectives are all interconnected. Figure 4.6a presents a non-exhaustive list of possible links, while Figure 4.6b presents the specific example of pressure coming from overfishing.

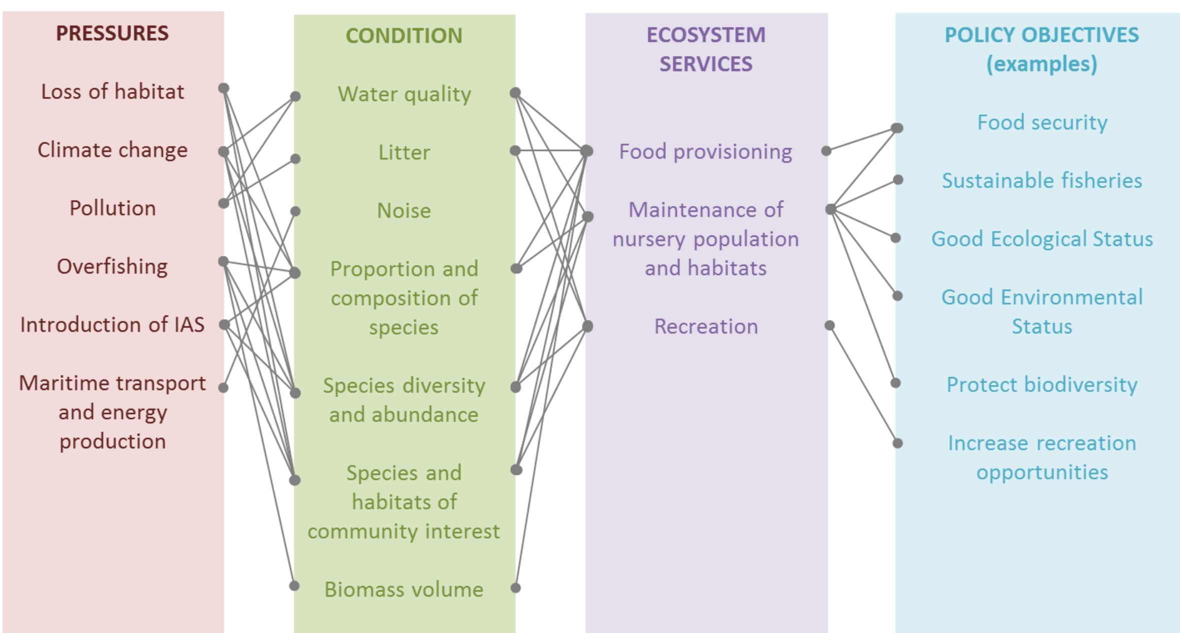

Figure 4.6a. Example of links between pressures, condition, ecosystem services and policy objectives in marine ecosystems

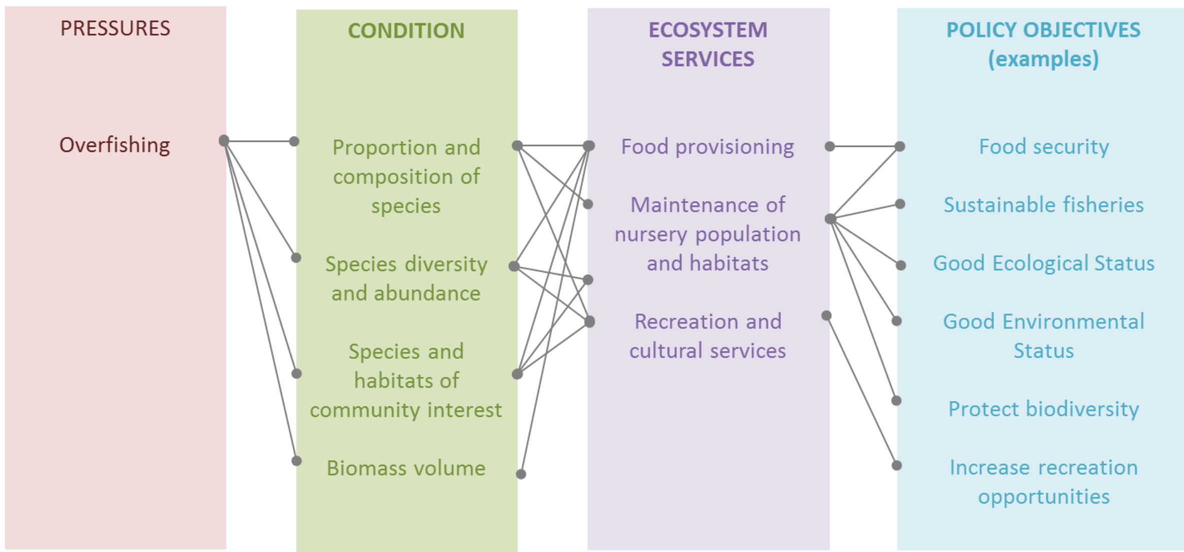

Figure 4.6b. Extraction of the nodes and links of Figure 4.6a to illustrate the example about overfishing

5 INDICATORS TOWARDS AN INTEGRATED ECOSYSTEM ASSESSMENT

5.1 A core set of policy relevant indicators for ecosystem condition

This chapter proposes a core set of cross-cutting ecosystem condition indicators (Tables 5.1, 5.2 and 5.3). This core set is based on the key indicators selected by the different ecosystem pilots (Chapter 4). These indicators have high policy relevance and many of them are instrumental to measure progress to targets under various policy frameworks. Datasets at EU level are available to quantify these indicators and to derive trend information relative to a baseline situation.

This core set of indicators can contribute to an integrated ecosystem assessment. An integrated ecosystem assessment (see also 2nd MAES report, Figure 2 on the common assessment framework; Maes et al., 2014) combines information about the extent and condition of ecosystems with an assessment of ecosystem services. An assessment of ecosystem condition is thus essential for mapping the capacity of ecosystems to deliver ecosystem services and to contribute to human well-being. To this end, it is important to recall that earlier MAES reports already propose a list of indicators for ecosystem services for the different ecosystem types (2nd and 4th MAES report; Maes et al., 2014; 2016)

5.1.1 Pressures

Table 5.1 includes the core set of pressure indicators for terrestrial and freshwater ecosystem types.

Land take is a pressure that affects almost all ecosystem types. Land take includes here all the different forms of conversion of one ecosystem type into an artificial land type or into another ecosystem type. It is expressed as the percentage change per year. For simplicity the indicator is referred to as "Land take" in Table 5.1 but it is reported under different names in the indicator tables of urban ecosystems (land annually taken for built up areas per person, Table 4.1), forests and woodland (Forest cover change and deforestation, Table 4.3) and the ecosystems reported by the nature pilot (Change of surface area due to conversion, Table 4.4). Conversion to forest (for wetlands) and intensification/extensification (for agroecosystems) are also important to assess habitat conversion and degradation.

Also the core set indicators for pressures related to nutrient enrichment underwent some slight simplification relative to the indicators which are recorded by the different ecosystem types in Chapter 4. To ensure consistent reporting, Table 5.1 retains three indicators: Critical load exceedance for nitrogen for most terrestrial ecosystem types and gross nitrogen balance and gross phosphorus balance for agroecosystems (cropland and grassland) and for rivers and lakes. For freshwater ecosystems the indicator refers to the inputs of nutrients at river basin scale.

All ecosystems suffer also from fragmentation. This pressure is explicitly mentioned by the forest pilot under habitat conversion using two indicators but here we include it in Table 5.2 under structural ecosystem attributes.

Other pressure indicators are ecosystem-specific, even if they are relevant for other ecosystem types. This is the case for ozone formation which may be relevant in urban ecosystems in relation to human health, for cropland in relation to crop damage and for other ecosystem types where vegetation may be impacted.

Although introductions of invasive alien species (IAS) are a threat to all ecosystem types, the indicator was not retained as key indicator for the specific terrestrial ecosystem types since data are not available for ecosystem-specific assessments. The European Alien Species Information Network[16] (EASIN) can, however, be used to assess IAS introductions per level 1 MAES ecosystem type (terrestrial, freshwater and marine). Therefore Table 5.1 suggests using an aggregated indicator at the level of terrestrial ecosystems.

Table 5.1. Core set of pressure indicators for terrestrial and freshwater ecosystem types.

Class	**Indicator**		**U**	**C**	**G**	**F**	**H**	**S**	**W**	**RL**
Habitat conversion and degradation	Land take* (conversion of the ecosystem type into another type, mostly artificial area)		●	●	●	●	●	●	●	●
	Intensification / extensification (AEI12)			●	●					
	Change in forest extent								●	
Climate change	n.a.									
Pollution and nutrient enrichment	Air pollution	Emissions of NO2, PM10, PM2.5	●							
		Formation of tropospheric ozone (ground level ozone)				●				
	Nitrogen loading	Gross nitrogen balance (SEBI 019) (AEI15)		●	●					●
		Critical load exceedance of nitrogen(SEBI 009)				●	●	●		●
	Gross phosphorus balance (AEI16)			●						●
Over-harvesting in forests	Long term ratio of annual fellings to net annual increment (SEBI 017)					●				
Introductions of invasive alien species	Number of annual introductions of invasive alien species** (number/year)		●							●

Table notes: U: Urban; C: Cropland; G: Grassland; F: Forest and woodland; H: Heathland and shrub; S: Sparsely vegetated land; W: Wetlands; RL: Rivers and lakes; ●: Key indicator for the ecosystem type; For units of the indicators: see Chapter 4 tables 4.1 to 4.5; SEBI: Indicator of Streamlining European Biodiversity Indicators; AEI: Agri-Environment Indicator; *Different ecosystem types used slightly different terminology for this indicator (see text for more explanation); **This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined as suggested by the merged cells in the table; for freshwater ecosystems (rivers and lakes) a separate assessment is possible.

Surprisingly, the core set reported in Table 5.1 does not include an indicator which describes the impact of climate change on the condition of ecosystems. Whereas chapter 4 lists several indicators to assess pressure from climate change, none of the indicators were considered key indicators. This is probably due to a poor representation of these indicators in present policy frameworks, difficulties in attributing ecosystem degradation to climate change and insufficient data coverage. It remains challenging indeed to isolate the effect of climate change from other pressures. Climate change produces a change in the temperature and precipitation quantity and intensity. Such indicators could be used for all ecosystems types, for instance the global and European temperature[17] and for marine ecosystems the sea surface temperature[18]. But it remains difficult to have

[16] https://easin.jrc.ec.europa.eu/
[17] https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-4/assessment
[18] https://www.eea.europa.eu/data-and-maps/indicators/sea-surface-temperature-2/assessment

indicators that show the effect of climate change on ecosystem functioning and conditions. The lack of a suitable indicator for measuring the impact of climate change on different ecosystems is a gap which needs to be addressed.

Although over-exploitation of natural resources is certainly among the major causes of ecosystems degradation, suitable indicators of over-harvesting are available only for forests ecosystem. This is related to the difficulty in establishing a sustainable level of exploitation and in quantifying the available stock of resources.

Loss of organic matter is a key indicator for pressure on agroecosystems (Table 4.2) but for simplicity we refer only to soil organic carbon (SOC) as indicator in Table 5.2. Loss of organic matter in agroecosystems can be quantified using a time series of SOC.

5.1.2 Ecosystem condition

Table 5.2 shows the core set of ecosystem condition indicators for terrestrial and freshwater ecosystem types. This set of indicators can be used to measure the condition of Europe's ecosystems in an integrated manner ensuring policy relevance and data coverage.

Five indicators emerge for a cross-cutting ecosystem assessment: conservation status of habitats, conservation status of species, coverage of ecosystems by Natura 2000, fragmentation and soil organic carbon.

The table effectively highlights the key contribution of the EU nature legislation (the Birds ad Habitats Directives) to measuring ecosystem condition. The conservation status of habitats and species reported under Article 17 of the Habitats directive and the status of birds collected under Article 12 of the Birds directive are crucially important to assess condition of almost all ecosystem types. Urban systems and croplands are not or partly covered. The coverage by Natura 2000 can be used as indicator of all ecosystem types including urban and cropland.

Fragmentation is a major determinant of ecosystem condition and appears as indicator across the different ecosystem types (sometimes under slightly different names including for instance also connectivity). Fragmentation can also be reported as pressure but for simplicity we included it here as condition indicator. Fragmentation is related to connectivity but they are not the same. Fragmentation is a structural indicator (whereas connectivity can be considered a functional indicator), can be measured in different ways and can be computed within and across ecosystems. In urban ecosystems it refers to fragmentation of green spaces; in freshwater ecosystems it refers to the fragmentation of rivers or the river network. In both ecosystem types it was not selected as key indicator but it is meaningful to include it in an integrated ecosystem assessment (and thus in Table 5.2) provided data is available.

Table 5.2. Core set of condition indicators for terrestrial and freshwater ecosystem types

Condition class	Indicator	U	C	G	F	H	S	W	RL
Environmental quality	Percentage of population exposed to noise	●							
	Percentage of population exposed to air pollution above the standards	●							
	Concentration of air pollutants (NO2, PM10, PM2.5, O3)	●							
	Percentage of population connected to urban waste water collection and treatment plants	●							
	Percentage of built up area	●							
	Tropospheric ozone (ground level ozone) concentration				●				
	Concentration of nitrogen, sulphate, sulphur, calcium and magnesium (SEBI 009)				●				
	Percentage of forest under management plan or equivalent				●				
	Nutrient and BOD concentration in surface water (SEBI 016)	●							●
	Water Exploitation Index								●
	Land cover in the drained area or floodplain								●
Structural ecosystem attributes (general)	Fragmentation (SEBI 013 and SEBI 014*)	●	●	●	●	●	●	●	●
	Percentage area of urban green space (or percentage of natural area within the city boundaries)	●							
	Share of High Nature Value farmland in agricultural area (SEBI 020) (AEI23)		●	●					
	Share of organic farming in utilised agricultural area (SEBI 020) (AEI4)		●						
	Livestock density		●						
	Deadwood (SEBI 018)				●				
	Forest area				●				
	Biomass volume (growing stock) (SEBI 017)				●				
	Ecological Status								●
Structural ecosystem attributes based on species diversity and abundance	Farmland Bird Indicator (SEBI 001) (AEI2.4.1)		●						
	Abundance and distribution of common forest birds (SEBI 001)				●				
Structural ecosystem attributes monitored under the EU nature directives	Percentage covered by Natura 2000 (SEBI 008) or by Nationally Designated Areas (SEBI 007)	●	●	●	●	●	●	●	●
	Conservation status and trends of species of Community interest (SEBI 003)		●	●	●	●	●	●	●
	Conservation status and trends of habitats of Community interest (SEBI 005)			●	●	●	●	●	●
	EU Population status and trends of bird species of Community interest (SEBI 003)		●	●	●	●	●	●	●
Structural soil indicator	Soil organic carbon	●	●	●	●	●	●	●	

Tables notes. U: Urban; C: Cropland; G: Grassland; F: Forest and woodland; H: Heathland and shrub; S: Sparsely vegetated land; W: Wetlands; RL: Rivers and lakes; ●: Key indicator for the ecosystem type; For units of the indicators: see Chapter 4 tables 4.1-4.5; SEBI: Indicator of Streamlining European Biodiversity Indicators (* SEBI 014 is under preparation); AEI: Agri-Environment Indicator.

Soil organic carbon (SOC) is another indicator with coverage across most ecosystem types. SOC is vital to diverse soil functions and ecosystem services and hence, a key determinant for ecosystem condition.

Water quality and air quality are part of the core set of indicators for environmental quality and are relevant for urban ecosystems and freshwater ecosystems. Ecological status is a crucial indicator for freshwater ecosystems.

High nature value farmland and the share of organic farming are key indicators for agroecosystems; deadwood and biomass are key indicators for forests.

Several indicators of the core set are based on biodiversity monitoring, in particular birds. Birds are well monitored across Europe. In addition, the recent assessment under Art.12 of the Birds Directive increased further the availability of highly relevant data for ecosystem condition assessment as well.

5.1.3 Marine ecosystems

A separate table was made for marine ecosystems. Table 5.3 lists the core set of indicators for pressure and ecosystem condition for four ecosystem types: marine inlets and transitional waters, and coastal ecosystems are merged in one column while shelf and open ocean are combined in second column.

Table 5.3. Core set of pressure and ecosystem condition indicators for marine ecosystem types

Class	**Indicator**	**TC**	**SO**
Climate change	Acidification	●	●
Pollution and nutrient enrichment	Contaminants (MSFD-D9)	●	●
	Nutrient discharge	●	●
Over-exploitation	Fish catch	●	●
	Fish mortality of commercially exploited fish and shellfish exceeding fishing mortality at maximum sustainable yield (MSFD-D3C1)	●	●
Introductions of invasive alien species	Number of annual introductions of invasive alien species (SEBI 010)	●	●
Environmental quality	Chemical Status	●	
	Nutrient and BOD concentrations (SEBI 015 and SEBI 016)	●	●
	Bathing water quality	●	
Structural ecosystem attributes (general)	Ecological status	●	
Structural ecosystem attributes based on species diversity and abundance	Spawning Stock Biomass (MSFD-D3C2)	●	●
	Age and size distribution of commercially-exploited species (MSFD-D3C3)	●	●
	Population abundance (MSFD D1C2)	●	●
Structural ecosystem attributes monitored under the EU nature directives	Conservation status and trends of habitats of Community interest (SEBI 005)	●	●
	Conservation status and trends of species of Community interest (SEBI 003)	●	●
	Population status and trends of bird species of Community interest	●	●
	Percentage of Natura 2000 and marine protected areas	●	●

Tables notes. TC: Marine inlets and transitional waters and Coastal ecosystems; SO: Shelf and Open ocean; ●: Key indicator for the ecosystem type; For units of the indicators: see Chapter 4 tables 4.6 and 4.7; MSFD: Indicator of the Marine Strategy Framework Directive; SEBI: Indicator of Streamlining European Biodiversity Indicators

In marine ecosystems, habitat loss is due rather to fishing activities (mostly bottom trawling), whereas pressures from climate change, pollution and nutrient enrichment, over-exploitation of fish stocks and invasive species are more relevant. Particular emphasis goes to indicators which are part of the Marine Strategy Framework Directive but also conservation status of habitats and species of the Habitat Directive covers parts of the marine ecosystems.

5.2 Links to other indicator frameworks and to the sustainable development goals

The MAES indicator framework for ecosystem condition contains several SEBI indicators (ref)[19]. The Pan-European SEBI initiative was launched in 2005. Its aim was to develop a European set of biodiversity relevant indicators – based on those already existing, plus new indicators as necessary – to assess and inform about progress towards the 2010 targets. From its inception SEBI is linked to the global framework set by the Convention on Biological Diversity with regional and national indicator initiatives. The 2010 set is currently upgraded and updated to serve the review of the Biodiversity Strategy to 2020.

Besides SEBI, the core set also integrates a number of Agri-Environmental Indicators (AEI) as well as indicators derived from the Habitats, Birds, Water Framework and Marine Strategy Framework Directives.

In particular some of the pressure indicators can also benefit from the EEA core set of indicators, e.g. regarding acidification and ozone exposure (CSI 005)[20] and air emission (CSI 040)[21].

The relevance of some of the indicators e.g. from the SEBI set and on water and air quality are also underlined by the fact, that they are used in the set of the EEA AIRS set, Annual Indicator Report Series (AIRS) — In support to the monitoring of the 7th Environment Action Programme [22]

This core set of indicators can also provide essential information to measure progress towards the sustainable development goals (SDG). The MAES indicators are particularly relevant for measuring progress to SDG 2 (zero hunger), SGD 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), SDG 14 (life below water) and SDG 15 (life on land).

5.3 A core set of indicators to support multiple policies for a sustainable future.

The analysis of the seven pilots involved a screening of suitable indicators for ecosystem pressures and condition, an assessment of their relevance for policy and a check for available data. The results are a set of indicator tables per ecosystem type including key indicators with high policy relevance and data coverage and a core set of indicators for an integrated ecosystem assessment. Because of the specific procedures followed to deliver the different indicator tables presented in this report the indicator framework also shows the key issues at stake.

5.3.1 Issues across ecosystems

Several indicators for pressures and ecosystem condition occur across all ecosystem types evidencing that a number of persistent environmental concerns remain and need continued policy attention and monitoring. For

[19] https://www.eea.europa.eu/publications/streamlining-european-biodiversity-indicators-sebi
[20] https://www.eea.europa.eu/data-and-maps/indicators/exposure-of-ecosystems-to-acidification-14/assessment
[21] https://www.eea.europa.eu/data-and-maps/indicators/main-anthropogenic-air-pollutant-emissions/assessment-5
[22] https://www.eea.europa.eu/airs

terrestrial ecosystems these are land take and habitat conversion as well as fragmentation; for freshwater and marine ecosystems nutrient enrichment caused by activities on land (e.g. agriculture), thus linking aquatic and terrestrial ecosystems. The MAES indicator framework can be used to monitor changes in these pressures in a spatially explicit way and it helps propose solutions to reduce pressures and enhance ecosystem condition.

Enhancing the connectivity of ecosystems by reducing fragmentation remains a key priority for ecosystem restoration. Developing new green infrastructure (GI) or restoring ecosystems which can serve as connectors between natural core areas are instrumental actions to reduce habitat and ecosystem fragmentation and thus to enhance ecosystem condition. The MAES core set of indicators for ecosystem condition can act as main tool for identifying and prioritizing areas for ecosystem restoration[23] and deployment of green infrastructure (GI). GI and ecosystem restoration are critical to achieve target 2 of the EU Biodiversity Strategy to 2020 and reconfirmed in the Action Plan for Nature, People and the Economy[24]. Under Action 12 of this plan, the Commission will promote strategic investments in nature through EU-level Green Infrastructure projects, with a range of financing sources, at a scale which transcends administrative boundaries. The overall objective is to promote EU's green infrastructure, to improve connectivity of Natura 2000 sites within and across national borders, linking up through biodiversity-rich areas where investments for ecosystem protection and restoration are prioritised, so as to enhance the delivery of essential ecosystem services throughout the EU territory.

Reducing the impact of nutrients emerges as another key priority. Nutrient loading remains a key pressure to ecosystems. While enhanced nitrogen fixation for mineral fertilizers has undeniable societal benefits, nitrogen and phosphorus are also powerful environmental pollutants. Nutrients from agriculture, waste water discharges and atmospheric deposition affect essential ecosystem services such as the provision of clean air and water, recreation, fisheries, forest products, aesthetics and biodiversity (Compton et al., 2011). The MAES indicator framework includes indicators which measure the sources and fate of nutrients as well as their impacts across all ecosystems stressing also that solutions to reduce nutrient enrichment have to come from cross-sectorial policy and decision making and collaboration.

Improving service provision by terrestrial ecosystems. Soil organic carbon (SOC) is one of the indicators with high relevance for all terrestrial ecosystems. SOC is a key indicator for ecosystem condition. Soil organic matter is the primary constituent of humus which plays a major role in maintaining soil functions and ecosystem services. It is important for soil structure and stability, water retention, soil biodiversity, and acts as a source of plant nutrients. Furthermore, soil is one of the major pools of carbon, thus, it plays a key role in climate regulation. The soils of the EU Member States are estimated to store between 73 and 79 billion tonne of carbon**.**
Increasing the SOC stock in soils delivers multiple benefits. It improves soil fertility and agricultural production and contributes to achieving the long-term climate targets. A key pressure is soil erosion, wild fires and the conversion of woodland and grassland to arable croplands, which is then compounded by deep ploughing, drainage, overuse of agrochemicals, and crop rotations with reduced proportion of grasses. Data for

[23] See also report of the restoration prioritisation framework from the European Commission: Lammerant, J, Peters, R, Snethlage, M, Delbaere, B, Dickie, I; Whiteley, G. (2013) Implementation of 2020 EU Biodiversity Strategy: Priorities for the restoration of ecosystems and their services in the EU. Report to the European Commission. ARCADIS (in cooperation with ECNC and Eftec).
[24] http://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/index_en.htm

estimating organic carbon in soils are collected in more than 25,000 locations across the EU under the LUCAS monitoring scheme (Land Use/Cover Area frame statistical Survey).

5.3.2 Specific issues per ecosystem type: application of the MAES indicator framework to enhance ecosystem condition in different ecosystems

The analysis of key indicators per ecosystem type reveals also how the MAES analytical framework can be used in sectorial policies. Different examples of how the MAES indicators for ecosystem condition can be used in policy are presented in chapter 4. Here we highlight some key issues per ecosystem type.

Urban ecosystems: Noise, air quality, thermal discomfort (too hot during the summer) and waste are principal challenges for cities. These challenges are addressed by the core set of condition indicators in combination with the indicators for urban ecosystem services in the 4th MAES report on urban ecosystems (Maes et al., 2016). Several of these indicators are designed to measure the exposure of the urban population to an environmental pressure. Such indicators address multiple societal challenges and are easy to communicate. They are scalable and can thus measure impact from very local to global scale. An example is the number of people exposed to a concentration of air pollutants above the legal threshold concentration. Also the delivery of ecosystem services such as fair access to green space or benefits from trees cooling the city can be assessed by including the exposure of people in the indicator. These indicators are relevant for measuring ecosystem condition but they also demonstrate how ecosystems in good condition can bring real and tangible benefits to people. Urban ecosystem assessments can also be used to inform or meet the targets of many other policies. Cities are important sources of noise and emissions of air pollutants and greenhouse gasses so relevant policies are the Environmental Noise Directive or the National Emission Ceilings Directive.

Agroecosystems: Agroecosystems in good condition deliver benefits to everyone. From the farmer who needs healthy and fertile soils for growing crops to the consumers of agricultural products to the society at large through the supply of regulating and cultural services. Keeping agroecosystems in good condition requires "an agricultural policy with strong commitment to deliver public goods and ecosystems services related to soil, water, biodiversity, air quality, climate action and the provision of landscape amenities" (European Commission, 2017). The MAES indicator framework on ecosystem condition (and ecosystem services) is therefore essential to help measure these objectives. Key indicators include the nitrogen balance, soil organic carbon, the share of High Nature Value farmland and organic farming, farming intensity and the occurrence of farmland birds. Conservation status of habitats and species (e.g. butterflies, pollinators) is a particularly important indicator to measure the condition of grasslands. Many types of grassland habitats are rich in plant species and they are dependent on good agricultural practices for their maintenance.

Forests: Forests provide a number of functions related to key services such as timber production, climate regulation and recreation, and are important for the conservation of many habitats and species. A key issue for forests is sustainable forest management which promotes multi-functional forests ensuring the delivery of forest products while maintaining and enhancing regulating and cultural ecosystem services, including their biodiversity.

Natural ecosystems: The MAES indicator framework for ecosystem condition proposes for all nature ecosystem types to rely on the monitoring schemes under the Nature Directives. Further efforts should thus go to enhance the conservation status of heathlands, sparsely vegetated habitats, and wetlands. Wetlands, such a peatland, have global significance (Ramsar Convention) and have an important functional role in the nutrient, carbon and water cycles[25]. Peat soils contain the highest concentration of organic matter of all soils. Peatlands are currently under threat from unsustainable practices such as drainage, clearance for agriculture, fires, climate change and peat extraction. The current area of peatland in the EU is estimated to be around 318,000 km^2, mainly found in the Northern latitudes. In addition to being major carbon stores, peat soils have an important role in the hydrological cycle and support important above ground habitats and their biodiversity.

Freshwater ecosystems: Ecological status is a key indicator for measuring the condition of aquatic ecosystems. Also different metrics related to water quality, such as the concentration of nutrients and pollutants are included in the indicator framework. The core set does not include yet indicators which measure the physical and structural integrity of the river network. Fragmentation is already identified as key pressure on terrestrial ecosystem types but also in freshwater ecosystems, fragmentation of stream habitats caused by tens of thousands of man-made barriers remains one of the major challenges to achieve good ecological status in the EU's rivers under the Water Framework Directive (WFD) as well as favourable conservation status of anadromous species (e.g. salmon, sturgeon) under the Habitats Directive (HD).

Marine ecosystems: The MAES core indicator set for pressures and ecosystem condition of marine ecosystems brings together indicators and data streams of several environmental directives (MSFD, WFD, BD and HD, Bathing Water Directive). This is particularly evident in transitional and coastal ecosystems. The coverage of these ecosystems by several environmental laws illustrates well their multi-functionality and also the multiple pressures to which marine ecosystems are subjected. Coastal zones are dynamic and complex systems which provide many benefits: fish and shellfish products, recreation, and regulating services such protection against flooding. Shallow ecosystems in coastal zones are essential nursery areas which support commercial fishery. A good condition of coastal and marine ecosystems is a precondition to continue supporting these services and delivering the associated benefits.

5.4 Knowledge gaps and enhancing knowledge and data

The MAES indicator framework builds to a large extent on currently existing environmental reporting streams. This is a deliberate choice. EU Environmental legislation aims to enhance the condition of specific habitats (under the Habitats Directive) and ecosystems (freshwater, transitional and marine under the Water and Marine Strategy Framework Directives).

The inclusion of conservation status, ecological status and environmental status into the MAES indicator framework for condition is an important further step to mainstream the benefits from healthy ecosystems between and into other policies. But it also creates data dependencies. In principle under the WFD the Member States report harmonized data every six years on the ecological status of aquatic ecosystems, based on national assessment methods that are intercalibrated. Differently, the data on habitat and species conservation status, provided every six years by the Member States, still suffer of some inconsistencies across the EU due to

[25] Cf. Wise use and conservation of wetlands. Communication from the Commission to the Council and the European Parliament. COM (95) 189 final, 29 May 1995

challenges in applying a common methodology. Consequently, a spatial interpretation of the Art.17 data is still not evident. Further improving the quality of Art.17 data during each reporting period is key for a wider usage of the data that goes beyond nature reporting on Member States and biogeographic region level.

An assessment of ecosystem condition per ecosystem type or across ecosystems based on the MAES indicator framework will likely result in positive relationships among the different condition indicators. A river basin which has a good ecological status of surface waters will most likely deliver assessments with a favorable conservation status of freshwater habitats. The nature of the relationships among the different indicators for ecosystem condition and between condition, pressures and services should be revealed in a European wide ecosystem assessment which is planned in the final phase of MAES and Action 5 (2018-2020). An integrated ecosystem assessment would also show how ecosystem condition differs in areas under different legal designation types (e.g., an ecosystem which is part of Natura 2000 while at the same time part of a nitrate vulnerable zone) and what is the impact of multiple designations on the capacity to deliver ecosystem services (e.g., Nikolaidou et al., 2017).

The different ecosystem pilots proposed specific indicators to assess the impact of climate change on ecosystem condition. Examples are urban temperature, soil moisture content of agroecosystems and forests, number of wild fires, or acidification in marine ecosystems. The core set does not contain a single indicator which can be used to assess the impact of climate change across ecosystem type. However, there is consensus (among the pilots) that such an indicator is not meaningful as impacts of climate vary across ecosystem types and across regions. An indicator-based assessment of past and projected climate change and its impacts on ecosystems and society is made available by the EEA (European Environment Agency, 2017).

Biodiversity indicators constitute a prominent part of the indicator framework. The condition indicators which are based on biodiversity include predominantly birds (common birds, farmland birds, Art.12 assessments under the Bird Directive). Red list species as well as species and habitats assessed under Art.17 of the Habitats Directive complete the picture. But also ecological status and several indicators of marine ecosystem condition are based on the presence or abundance of particular species. The inclusion of many biodiversity indicators and the earlier identified synergies with the SEBI indicator set makes the MAES indicator framework useful for measuring progress to European and global biodiversity targets. However, a number of important taxa is missing from this framework and more efforts are needed to collect better data, notably on pollinators. The EU is preparing a new initiative on pollinators and pollination. Pollinator species are crucially important to sustain agricultural production of fruits and vegetables but they suffer declines due to a combination of pressures. Establishing a knowledge base on the distribution and abundance of main pollinator species is an objective of the new initiative. Pollinator based ecosystem condition indicators would complement the framework and demonstrate the link between biodiversity and ecosystem services.

Natural capital accounts constitute a key instrument to harmonize data of ecosystem condition and to improve integrated data collection and assessment. KIP INCA will develop and test accounts for ecosystem extent, ecosystem condition and ecosystem services (see chapter 2). The outcomes of this report are therefore a direct input to the KIP and provide a set of indicators which can be used to develop and test the ecosystem condition accounts.

6 CONCLUSIONS AND OUTLOOK

The analytical framework for ecosystem condition is the keystone of the whole action 5 of the EU Biodiversity Strategy to 2020. This is because ecosystem condition is a unifying concept as it brings legal requirements about the status of habitats, species and ecosystems and the capacity of ecosystems to provide ecosystem services into a common framework, including ecosystems and habitats without status definition under the European environmental legislation. Healthy, productive and resilient ecosystems are key to achieve different targets of the EU Biodiversity Strategy to 2020. Of particular importance is spatially explicit knowledge about ecosystem condition and the different pressures that act on ecosystems for deciding on a prioritisation framework for ecosystem restoration. But ecosystem condition indicators are also essential to monitor the successful implementation of many other policies including agriculture, forestry, fishery, water, climate or public health.

The added value of this indicator framework is that for the first time a comprehensive and consistent list of indicators for ecosystem condition is collected. The indicators can be used to map and assess ecosystem condition per ecosystem type but the framework also allows horizontal assessments across different ecosystems. Moreover, a core set of policy relevant condition indicators can be used as a starting point for an EU wide integrated ecosystem assessment.

The analytical framework for ecosystem condition is tailored towards policy use. Different examples show that the framework can be used to (1) put different policy options or policy actions in an ecosystem perspective; (2) to assess how policy actions have an impact on ecosystem condition; (3) to assess the present situation and see where actions can be taken to enhance ecosystem condition; (4) to link ecosystem based approaches to other policies, and (5) to finally provide a common framework for ecosystems under legally defined status definition together with ecosystems which are not the object of environmental legislation.

The analytical framework and the indicators assessed by ecosystem type are also useful for identifying limitations and data gaps. A close view of the indicator tables in Chapter 4 reveals areas where new datasets could improve the current situation regarding indicators and data. For example, improving the spatial and temporal resolution, and expanding the observational period of the datasets (including past periods), as well as its pan-European completeness, are aspects requiring further efforts. More data and information on changes in pressures, ecosystem condition and biodiversity will become available by new (e.g., Copernicus programme), re-launched (e.g., air pollution impact assessment of the NEC Directive) or improved (e.g., HD, BD reporting) data flows which has to be integrated into the current indicator framework as presented in this report.

Now the analytical framework must be tested and used. It is expected to apply the framework with real data in 2018 with a view to deliver an integrated assessment of the state of ecosystems and their services in EU in 2019. Many of the conceptual questions touched upon in section 2 will be possible to verify in this phase. As such it will complement the knowledge base for the final evaluation of the EU Biodiversity Strategy to 2020. It will also be applied for the development of pilot accounts in the context of KIP-INCA to achieve better outreach of environmental information into the community which uses mostly statistical data for reporting and decision making. It will provide a key contribution to the evidence base for the post-2020 EU biodiversity policy framework.

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ABBREVIATIONS

AEI	Agri-Environmental Indicator
AIRS	Annual Indicator Report Series
Art.17	Article 17 (assessments of habitats and species under the EU Habitats Directive)
BD	Bird Directive
BISE	Biodiversity Information System for Europe
BOD	Biological Oxygen Demand
BQE	Biological Quality Elements
CAP	Common Agricultural Policy
CBD	Convention of Biological Diversity
CFP	Common Fisheries Policy
CI	Composite Index
CICES	Common International Classification of Ecosystem Services
CIRCABC	Communication and Information Resource Centre for Administrations, Businesses and Citizens.
CMEF	Common Monitoring and Evaluation Framework for monitoring and evaluation of all rural development interventions
EASIN	European Alien Species Information Network
EC	European Commission
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
fAPAR	fraction of Absorbed Photosynthetically Active Radiation
Fmsy	Fishing mortality consistent with achieving Maximum Sustainable Yield (MSY)
FUA	Functional Urban Area
GI	Green Infrastructure
GES	Good Environmental Status
HD	Habitats Directive
HNV	High Nature Value
IACS	Integrated Administration and Control System
IAS	Invasive Alien Species
ICP	International Co-operative Programme
IUCN	International Union for Conservation of Nature
KIP INCA	Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting
LAI	Leaf Area Index
LPIS	Land Parcel Identification System
LU	Livestock Units
LUCAS	Land Use/Cover Area frame statistical Survey
MA	Millennium Ecosystem Assessment
MAES	Mapping and Assessment of Ecosystems and their Services
MS	EU Member States
MSFD	Marine Strategy Framework Directive
NEC	National Emission Ceiling
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Production
NUTS	Nomenclature of territorial units for statistics
SDG	Sustainable Development Goal
SEBI	Streamlined European Biodiversity Indicators
SEEA-EEA	System of Environmental Economic Accounts - Experimental Ecosystem Accounts
SOC	Soil Organic Carbon
TEEB	The Economics of Ecosystems and Biodiversity

UAA	Units of Agricultural Area
UK NEA	UK National Ecosystem Assessment
VCI	Vegetation Condition Index
WFD	Water Framework Directive

ANNEX 1: GLOSSARY OF TERMS

Analytical framework: An analytical framework consists of a conceptual framework complemented with the main definitions and classifications needed for its operational use (based on OECD, 2016)

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. Assessments are inherently transdisciplinary processes where scientists and stakeholders work together to match data to the elements of a shared a conceptual framework (based on Parson, 1995).

Assets: Economic resources (TEEB, 2010). Ecosystems with their respective extent and condition can be considered as *ecosystem assets* (based on SEEA-EEA, 2012).

Benefits: Positive change in wellbeing from the fulfilment of individual or societal needs and wants (based on TEEB, 2010).

Biodiversity: The variability among living organisms from all sources, including inter alia terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part, this includes diversity within species, between species, and of ecosystems (based on CBD, 1992).

Capacity (for an ecosystem service): The ability of a given ecosystem to generate a specific ecosystem service in a sustainable way (based on SEEA-EEA, 2012).

Conceptual framework: A model describing the relevant elements of a physical or social system and the main connections between them for the purposes of understanding and communication

Conservation status (of a natural habitat): The sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species (EEC, 1992).

Conservation status (of a species): The sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations (EEC, 1992).

Drivers of change: Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. A direct driver of change unequivocally influences ecosystem processes and can therefore be identified and measured to differing degrees of accuracy; an indirect driver of change operates by altering the level or rate of change of one or more direct drivers (MA, 2005).

Ecological status (of freshwater ecosystems): a legally defined expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters (EC, 2000).

Ecological value: Non-monetary assessment of ecosystem integrity, health, or resilience, all of which are important indicators to determine critical thresholds and minimum requirements for ecosystem service provision (TEEB, 2010).

Economic valuation: The process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) in monetary terms (TEEB, 2010).

Ecosystem: 1 *(in a general context)*: A dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit. Humans may be an integral part of an ecosystem, although 'socio-ecological system' is sometimes used to denote situations in which people play a significant role, or where the character of the ecosystem is heavily influenced by human action (based on CBD, 1992 and MA, 2005). 2 *(in the MAES context)*: An ecosystem type.

Ecosystem accounting: Ecosystem accounting is a coherent and integrated approach to the measurement of ecosystem assets and the flows of services from them into economic and other human activity (SEEA-EEA, 2012)

Ecosystem assessment: A social process through which the findings of science concerning the causes of ecosystem change, their consequences for human well-being, and management and policy options are brought to bear on the needs of decision-makers (UK NEA, 2011).

Ecosystem condition: The physical, chemical and biological condition or quality of an ecosystem at a particular point in time (definition used in MAES). The Millennium Ecosystem Assessment has defined ecosystem condition as the capacity of an ecosystem to deliver ecosystem services, relative to its potential capacity (MA 2005). The SEEA-EEA defines ecosystem condition as the overall quality of an ecosystem asset in terms of its characteristics.

Ecosystem degradation: A persistent decline in the condition of an ecosystem.

Ecosystem extent: The spatial area covered by an ecosystem or ecosystem type (based on SEEA-EEA, 2012).

Ecosystem process: Any change or reaction, which occurs within or among ecosystems, physical, chemical or biological. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy (MA, 2005).

Ecosystem service: The contributions of ecosystems to benefits obtained in economic, social, cultural and other human activity (based on TEEB, 2010 & SEEA-EEA, 2012). The concepts of 'ecosystem goods and services', 'final ecosystem services', and 'nature's contributions to people' are considered to be synonymous with ecosystem services in the MAES context.

Ecosystem status: Ecosystem condition defined among several well-defined categories with a legal status. It is usually measured against time and compared to an agreed target in EU environmental directives (e.g. Habitats Directive, Water Framework Directive, Marine Strategy Framework Directive), e.g. "conservation status".

Ecosystem type: A specific category of an ecosystem typology.

Ecosystem typology: A classification of ecosystem units according to their relevant ecosystem characteritics, usually linked to specific objectives and spatial scales.

Environmental status (of marine ecosystems): the overall state of the environment in marine waters, taking into account the structure, function and processes of the constituent marine ecosystems together with natural, physiographic, geographic, biological, geological and climatic factors, as well as physical, acoustic and chemical conditions, including those resulting from human activities inside or outside the area concerned (EC, 2008).

Flow (of an ecosystem service): The amount of an ecosystem service that is actually mobilized in a specific area and time (based on Openness, 2014).

Habitat: 1. *(in a general context)*: The physical location or type of environment in which an organism or biological population lives or occurs, defined by the sum of the abiotic and biotic factors of the environment, whether natural or modified, which are essential to the life and reproduction of the species (based on EEC, 1992). 2 *(in a MAES context)*: A synonym of 'ecosystem type'.

Human well-being: A state that is intrinsically (and not just instrumentally) valuable or good for a person or a societal group, comprising access to basic materials for a good life, health, security, good physical and mental state, and good social relations (based on MA, 2005).

Indicator: An indicator is a number or qualitative descriptor generated with a well-defined method which reflects a phenomenon of interest (the indicandum). Indicators are frequently used by policy-makers to set environmental goals and evaluate their fulfilment (based on Heink & Kowarik, 2010).

Mapping: The process of creating a cartographic representation (map) of objects in geographic space. In the MAES context mapping means a spatially detailed assessment of the elements of the MAES framework, which aims inter alia at creating cartographic representations of the studied elements (based on OpenNESS, 2014).

Pressure: Human induced process that alters the condition of ecosystems.

Socio-economic system: Our society (which includes institutions that manage ecosystems, users that use their services and stakeholders that influence ecosystems).

Soil erodibility (K-factor): expresses the susceptibility of a soil to erode.

Value: The contribution of an action or object to user-specified goals, objectives, or conditions (MA, 2005).

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