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Fact sheets on ecosystem condition: a synthesis

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1. Introduction

The EU Biodiversity Strategy to 2020 requests that ecosystems and their services should be assessed in Europe (Maes et al., 2013; 2014). This involves assessing the condition of the ecosystems, since adequate ecosystem service (ES) provision requires healthy ecosystems in good condition (Maes et al., 2014). But ecosystem condition is an elusive concept, and there is no 'default' way on how it should be measured. In 2017 and 2018 the European Topic Centre for Biological Diversity (ETC/BD) worked on exploring functional relationships between ecosystem condition and services. This activity led to the creation of a series of fact sheets which explore the ways how ecosystem condition can be meaningfully defined and measured for various services in various ecosystem types (ET). There are two main types of fact sheets: ecosystem service fact sheets, and ecosystem type fact sheets. The fact sheets produced in 2018 are summarized in Table 1.1.

Table 1.1: **The ecosystem services and ecosystem types studied in detail** during the 'functional relationships' work, and the fact sheets summarizing *ecosystem condition – ecosystem service* (EC~ES) relationships created by ETC/BD.

Topic of the fact sheets	References
***Ecosystem service fact sheets**: which characteristics of the ecosystems (in general) are relevant for a specific service?*	
Pollination	Czúcz & Götzl, 2018; Götzl et al., 2017
Pest regulation	Götzl & Czúcz, 2018a
Carbon sequestration (atmospheric regulation)	Schwaiger & Czúcz, 2018
Flood protection (water flow regulation)	Czúcz & Sonderegger, 2018a
Water quality regulation	Götzl & Czúcz, 2018b
Recreation (aesthetic landscapes)	Czúcz & Sonderegger, 2018b; Götzl et al., 2017
Timber production*	
Freshwater fishing*	
Erosion protection (mass flow regulation)*	
Air quality regulation*	
Ecosystem type fact sheets	
Grassland	Czúcz, 2018a; Hönigová et al., 2011
Woodland and forest	Czúcz, 2018b
Wetlands	Czúcz, 2018c
Urban*	
Cropland*	
Heathland and shrub*	
Sparsely vegetated land*	
Rivers and lakes*	
Marine inlets and transitional waters*	

** topics that were included in the systematic review, but have not been elaborated as fact sheets.*

The fact sheets are relatively short reports that follow a 'standard' structure. They explain the ecosystem characteristics that were found to be relevant for the studied service / ecosystem type, and provide a 'gap analysis' by matching these characteristics to the condition indicators identified during the EU MAES condition assessment process (Erhard et al., 2016; Maes et al., 2018). In addition, particular emphasis is given to conceptual and technical issues related to interpreting the studied service, or defining/delimiting the studied ecosystem type, and positioning them in the context of the EU MAES assessment (the 'boxes' of Fig. 1.1). The fact sheets also contain a lot of supporting material in the form of harmonized tables and annexes.

This report is the summary document for all of these fact sheets, giving a short methodological overview, and a detailed account of the cross-cutting topics not or just partially covered in the individual fact sheets. A more detailed description of the underlying systematic review is available in the first output of this activity (Czúcz et al., 2017), and detailed discussions pertaining to each ecosystem type and ecosystem service can be found in the individual fact sheets.

1.1 Policy context

In line with the fundamental role nature and its services play in the healthy functioning of human society and economy, Target 2 of the EU Biodiversity Strategy calls member states to maintain and restore the ecosystems and their services. In order to meet this goal ecosystems, their condition, and the ecosystem services (ES) they provide should be assessed. The EU MAES assessment framework (Maes et al., 2013; 2014), and the underlying cascade model (Potschin & Haines-Young 2011) provides a logical and operative structure for such assessments (Fig. 1.1). A key element of the MAES framework is the elusive concept of ecosystem condition, which can establish the otherwise missing link between the various ecosystem types (ET) and the services enjoyed by humans, as emphasized by the following operative definition (Czúcz & Condé, 2017; Czúcz et al., 2017):

> ***ecosystem condition***: "the overall quality of an ecosystem unit, in terms of its main characteristics underpinning its capacity to generate ecosystem services".

This definition relies on an instrumental perspective (those characteristics are important which influence the delivery of ecosystem services), which also entails a hidden value choice (should we protect nature for itself, or 'just' because it gives us services?) Nevertheless, it must be noted that the whole concept of ecosystem services is inherently rooted in instrumental values (Justus et al., 2009; Davidson, 2013), so taking an instrumental perspective for defining ecosystem condition also improves its compatibility with ES assessments. Furthermore, this instrumental definition also comes with a range of further practical advantages:

(1) it provides an objective and criterion method for identifying which characteristics of the ecosystems should be considered as 'relevant' for an ecosystem condition assessment (see more in Chapter 3.1); and
(2) it links ecosystem condition (and its concrete indicators) to the ecosystem services, thus providing solid and objective arguments for the conservation / restoration of ecosystems.

There are many other ways for defining ecosystem condition, and other definitions which do not link the condition to services can be seen as equally valid. Nevertheless, its inherent compatibility with the MAES assessments, and two advantages make this instrumental definition a good choice for use in the EU MAES assessment.

In addition to the MAES assessment work, a developed system of interlinked indicators of ecosystem condition and ecosystem services would provide a significant tool for further policy domains. A set of 'evidence-based' condition indicators would fulfil the metaphor of capital stocks (=ecosystems) being linked to revenue flows (services) and engage the concept of natural capital. Such condition metrics could, in fact, be a 'game changer' in the context of ecosystem accounting (Hein et al., 2016; MAES-INCA, 2018). Meaningful condition metrics linked to service provisioning capacities can also be useful in policy domains where the level of degradation needs to be measured for a successful implementation (e.g. restoration targets, Lammerant et al., 2013). Accordingly, well-founded and widely accepted condition metrics can potentially provide convincing solutions for settling the "how to measure the 15%" type of questions, currently hampering the implementation of European (EU Biodiversity Strategy, Target 2) and global (CBD Aichi Target 15) biodiversity targets. Similarly, good condition metrics are also vital to evaluate the magnitudes of losses and compensations in the

context of the flexibility mechanisms proposed e.g. in the No Net Loss initiative (EU Biodiversity Strategy, Action 7) or the Sustainable Development Goal 15 (Target 3).

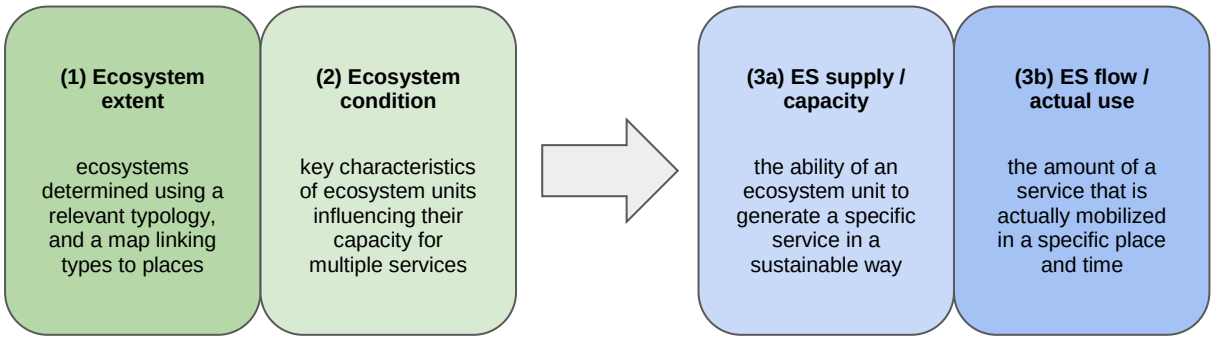

Figure 1.1: A simplified representation of the MAES conceptual framework, based on Maes et al. (2014), Burkhard et al. (2018), and MAES-INCA (2018). The boxes describe the main elements which need to be determined, mapped and assessed during the EU MAES assessment process. The numbers in the boxes correspond to the original graph of the MAES framework (Figure 2 in Maes et al. 2014, p. 22). This linear alignment of the boxes puts more emphasis on the dependency / connectivity of services on condition than the original figure focusing more on ecosystem typology.

1.2 Scientific context

According to the instrumental definition given above, the concept of 'ecosystem condition' can be operationalized by identifying those *measurable characteristics* of ecosystems that *influence* the supply of *several services* at the same time. Exploring links between ecosystem characteristics and ecosystem services (*'EC~ES' relationships*) has previously been one of the most popular domains in ecological research in the last ~15 years. A substantial amount of primary research studies exist which try to find statistically significant relationships between the characteristics of a specific ecosystem and the supply of a specific ES from that ecosystem. This surge of primary studies created a need for overview / review studies, aiming to reconstruct the big picture (Table 1.2). However, until recently, most of the review studies had typically structured their synthesis in a way that cannot address ecosystem condition in a systematic way, which can be used for operationalizing this concept (Table 1.2).

However, some of the reviews, including the consecutive reviews of Harrison et al. (2014) and Smith et al. (2017) did still contribute considerably to the operationalization of the ecosystem condition concept. The latter and more advanced one (which was performed in the context of the OpenNESS EU FP7 project) involved 13 ES (see Table 2.1), for each of which 60 scientific papers had been selected, following a standardized search methodology based on a high number of customized keywords (Harrison et al. 2014, Pérez-Soba et al, 2015). However, the OpenNESS approach also had a few considerable shortcomings, including (1) a lack of article screening (original research hypothesis testing papers were mixed with practical assessments, and review papers, etc. in the review); (2) weak spatial/thematic focus (papers represent all ETs) of the world with an uneven coverage, highly biased towards northern temperate terrestrial ecosystems); (3) an overly complicated classification system (see Czúcz et al. 2017 for a discussion); and (4) a high number of reviewers (16) with relatively little training leading to a database of uneven quality. Analysing the OpenNESS systematic review database, Smith et al. (2017) also had to face several of the issues previously mentioned, ultimately abandoning the complex categories of the original review, and reclassifying the records into a limited number of five 'natural capital attributes'.

Table 1.2: Major review studies which have addressed some aspects of the functional relationships between ecosystem characteristics and ecosystem services

Literature reference*	Short description
Cardinale et. al. 2012, Mace et al. 2012, Byrnes et al. 2014, Balvanera et al. 2014, Duncan et al. 2015, Ricketts et al. 2016, ...	Reviews restricted to biodiversity~ES relationships, typically conceptualizing biodiversity in a way which is largely incompatible with ecosystem assessments. There is a very high number of such reviews.
Harrison et al. 2014	Systematic review of 530 papers for 11 ES identifying relevant biotic and abiotic attributes of 'ecosystem service providers'
Maes et al. 2016	Broad but non-systematic review which constructed a long list of potential condition indicators with little synthesis and no evidence rating
Wong et al. 2015, Maseyk et al. 2017	Non-systematic reviews principally promoting a research agenda, actually urging for the type of systematic review that is shown in this report
Smith et al. 2017	A systematic review extending the work of Harrison et al. (2014) with new attributes, new ES, and new papers (also discussed in the text below)

* studies identified with a Web of Science search with the following search string: "(TS= ((systematic review OR meta analysis) AND ecosystem service* AND (characteristics OR condition* OR natural capital))", excluding the reviews for a single ES or ET.

2. Methods

In 2017 ETC/BD performed a thorough 'reanalysis' of the original data tables underlying the OpenNESS systematic review (Smith et al., 2017) in order to extract additional information that can be used in the context of the EU MAES assessment (Czúcz et al. 2017). Only *original research papers* which tested some *hypotheses (EC~ES relationship)* in *European* ETs were considered. The scope of the work was also restricted in terms of ES, discarding three services due to conceptual considerations (Table 2.1). For each of the remaining ES a fixed number (10) of relevant papers were randomly selected, which constituted the basis for this work.

The selected papers were then analysed individually, and all of the EC~ES relationships documented by the OpenNESS reviewers were transcribed following the MAES ecosystem typology (Maes et al., 2013) and additional simplified typology of ecosystem (=site & landscape) characteristics. This latter typology was designed to offer an intermediate level of detail between the overly simplistic five classes and the overly complex system of the original variables. The following criteria inspired the design of this typology: (1) it should reflect the needs of regional, national and continental-level ecosystem assessments, (2) it should remain compatible with the simple classes from Smith et al. (2017), and (3) it should be as clear, well-defined and simple as possible. The classes ('object' and 'attribute' types) of this typology, and all other details of the transcription process are described more in detail by Czúcz et al. (2017).

Table 2.1: The ES and the papers studied in the OpenNESS database (Smith et al. 2017) and its reanalysis by ETC/BD (Czúcz et al. 2017)

ES id	ES name (OpenNESS)	CICES 5.1[a]	OpenNESS[b]	reanalysed[c]
timber	Timber production	1.1.5.2*	12	10
fw.fish	Freshwater fishing	1.1.6.1 (3.1.1.2*)	10	10
pollin	Pollination	2.2.2.1	25	10
pest	Pest regulation	2.2.3.1	28	10
carbon	Atmospheric regulation (carbon sequestration)	2.2.6.1p	11	10
erosion	Mass flow regulation (erosion protection)	2.2.1.1	23	10
flood	Water flow regulation (flood protection)	2.2.1.3	20	10
w.qual	Water quality regulation	2.1.1.x, 2.2.5.x	11	10
sp.recr[d]	*Species-based recreation*	*3.1.1.1*, 3.1.1.2**	*3*	*0*
aesth	Aesthetic landscapes	3.1.2.4	24	10
w.quant[e]	*Potable water (quantity)*	*4.2.1.1-2, 4.2.2.1-2*	–	*0*
food.pr[e]	*Food production (cultivated crops)*	*1.1.1.x (1.1.3.x)*	–	*0*
a.qual	Air quality regulation	2.2.6.2*	13	10

a: CICES v5.1 class codes (based on Haines-Young & Potschin, 2018);
b: number of 'relevant' papers in the OpenNESS dataset (original research for European ecosystems);
c: number of papers reanalysed by Czúcz et al (2017);
d: species-based recreation was dropped due to a conceptual overlap with aesthetic landscapes and the low number of 'relevant' reviews;
e: potable water and cultivated food crops were dropped due to conceptual considerations (w.quant is an abiotic service, and food.pr is provided through economic activities in highly anthropogenic managed systems)
** the match with the CICES class is just partial*

After having created this structured and systematic overview on the functional relationships, the characteristics identified as relevant were matched to available indicators followed by a gap analysis. Available indicators were identified based on the indicators listed in the 5th MAES report (Maes et al., 2018) for terrestrial ecosystem types: cropland, grassland, forest, heathland, sparsely vegetated land (SVL), and wetland, as defined in Maes et al. (2013). The indicators were matched to the topics and they were scored according to their **relevance** for each specific ecosystem service and ecosystem type. The relevance of the indicators was based on expert interpretation of the results of the systematic review. It was interpreted as the number of papers documenting a significant

relationship for the specific ES or ET. In addition to the relevance, two further aspects of indicator 'usefulness' were scored which included: **representativity** estimating the degree to which the indicator represents the indicandum (i.e. the underlying condition aspect); and **availability** which synthesizes aspects of data availability, reliability, and spatial resolution. Representativity and availability were considered to be consistent across all ecosystem types and services. All aspects of indicator usefulness were scored at a 3-grade ordinal scale, analysing also the metadata collected by the MAES pilots, complemented with further literature search wherever it was necessary. All scores were assigned as objectively and consistently as possible.

In parallel with analysing and scoring the indicators, new suggestions for simple and straightforward indicators were also sought to cover the gaps, i.e. the topics not covered adequately by the indicators listed, and added to the 'repository'. The necessary 'MAES metadata' for the new indicators were collected as much as possible, and scores were assigned to the new indicators – with the availability score reflecting the efforts and uncertainties related to their implementation.

According to their resulting scores, the indicators were prioritised, listed and discussed in the individual fact sheets (see Table 1.1) and in this summary report. In each fact sheet, a number of key indicators are identified which can potentially represent an 'optimal' indicator set combining all aspects of usefulness (relevance, representativity and availability) and parsimony considerations (see Chapter 3.2) for the studied ecosystem service or ecosystem type. Finally, custom made network diagrams were elaborated to visually summarize the link between key indicators, their underlying characteristics ('indicanda'), and relationships to the various ecosystem types / services. The whole 'indicator repository' is presented in Annex 1 with all MAES metadata, as well as the scores for representativity and availability. The relevance scores can be found in the individual fact sheets and in Table 3.3 and 3.4 for the key indicators. The various sets of key indicators are harmonized based on a number of selection criteria in the following chapter.

3. Results

3.1 Relevant ecosystem characteristics

In the systematic review altogether 100 papers were analysed, in which 295 EC~ES relationships could be identified (Czúcz et al., 2017). Due to the selection method, the studied services are relatively evenly represented in the review (Fig 3.1a), but there is a considerable heterogeneity in the representation of the different ecosystem types in sample (Fig 3.1b). There is a high bias towards the most prevalent (and most intensively used) ecosystem types, namely croplands, grasslands and forests. However, given that these ETs cover more than 80% of the European land surface (Weiss & Banko, 2018), the whole review and its results can be considered as representative for terrestrial ecosystems in Europe.

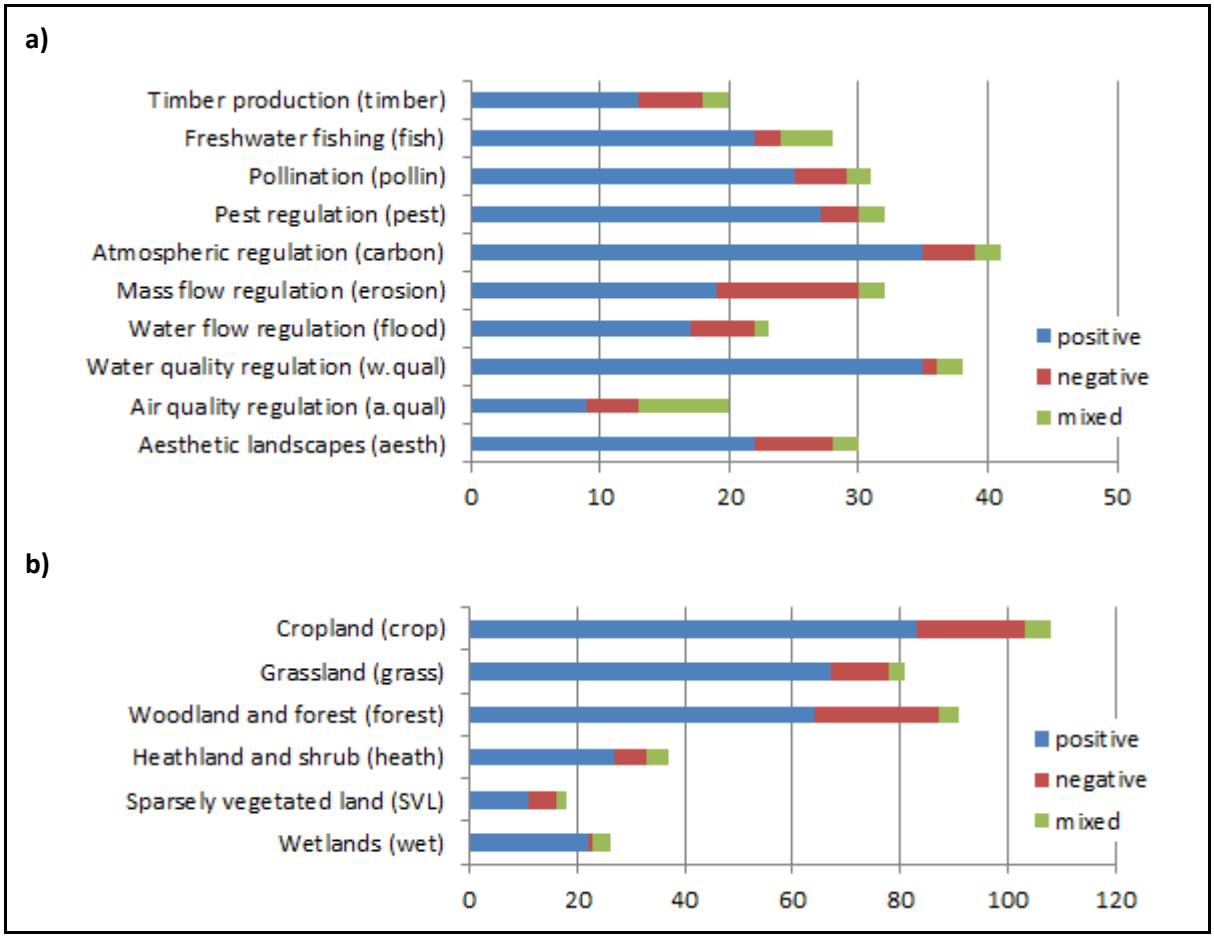

Figure 3.1: The number and direction (positive, negative, mixed) of documented relationships between ecosystem characteristics and ecosystem services ('EC~ES' relationships) grouped according to ecosystem services (a), and ecosystem types (b)

Figure 3.2 and Table 3.1 show the distribution of EC~ES relationships for the groups of ecosystem characteristics considered during the study. The distribution of relationships is far from even for the various groups of characteristics, and although the pattern might be somewhat affected by the paper selection bias, the number of documented relationships can be seen as a '*degree of evidence*' or '*degree of relevance*' for each characteristic.

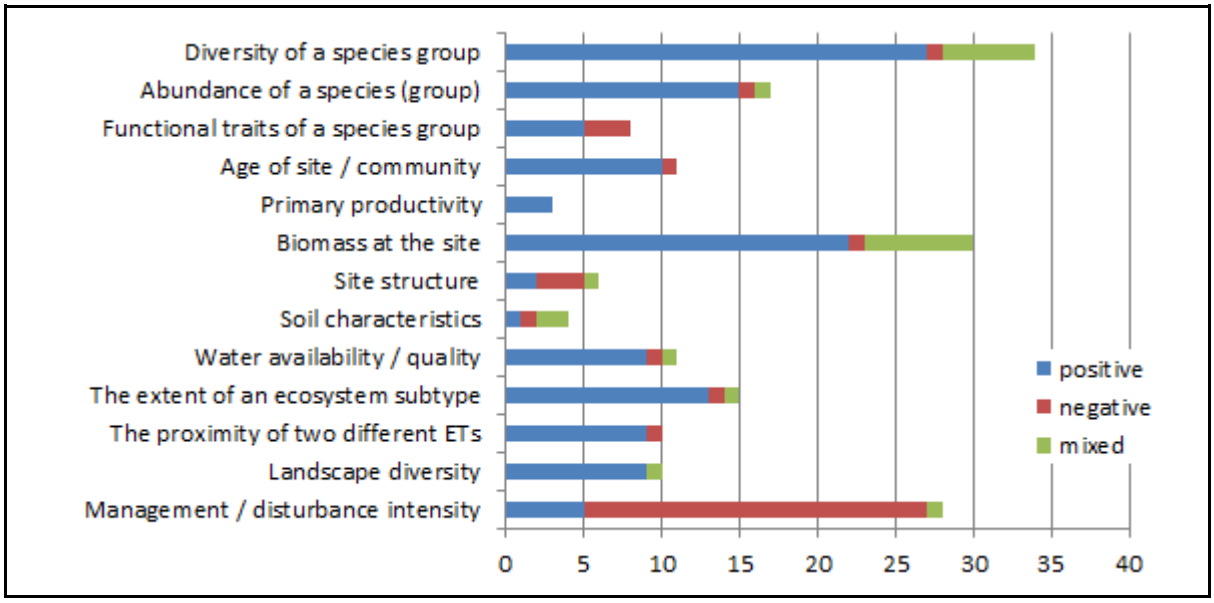

Figure 3.2: The number and direction (positive, negative, mixed) of documented EC~ES relationships for each group of characteristics studied

There are three groups of characteristics that seem to be of key importance in terms of their influence on ecosystem services: the biodiversity of the ecosystems, the mass of living matter (biomass) accumulated, and the intensity of human management activities. All of these characteristics affect a wide, but slightly different range of ES. The intensity of management (and disturbances) seems to affect almost all of the services to a similar degree, whereas biodiversity and biomass seem to exert a preferential influence: they affect some services more than other ES. The impact of biodiversity and biomass characteristics seems to be complementary: those ES that are highly influenced by the 'mass' of green tend to be less affected by its composition, and vice versa. More specifically, biomass exerts most influence on a specific group of important regulating ES (e.g. *flood control*, *erosion control*, *carbon sequestration*, and *air* and *water quality regulation*); whereas biodiversity seems to affect the rest of the services (including provisioning, cultural, and the few remaining regulating services: *pollination*, *pest control*).

For most ecosystem characteristics most of the relationships are positive: the 'stronger' the characteristic is, the more services the ecosystem can provide (i.e. higher values of the EC indicator imply higher values of the ES indicator in the underlying scientific study). The intensity of human management (and natural disturbances) seems to be an exception to this general rule: a more intensive management seems to lead to a reduced availability of services. It is important to note though, that most management activities have a target ES (which is typically a provisioning ES, e.g. the provision of *food* in croplands, *timber* in forests, or *fodder* in grasslands), but the relationship between management intensity and the target ES is rarely addressed in scientific studies (because it is generally considered trivial). Consequently, these trivially positive relationships between management (e.g. felling) intensity indicators and their target ES (e.g. timber) was not covered by our systematic review, either.

Table 3.1: Results of the systematic review: ecosystem characteristics that have been documented to influence the supply of any ecosystem service in any ecosystem type (Czúcz et al., 2017). Tot / Pos / Neg / Mix: the number of papers which document any (total) / pos(itive) / neg(ative) / mix(ed) relationships between the studied characteristics and a specific service.

Characteristic group	ot	os	eg	lix	Ecosystem types*	Ecosystem services**
Diversity of a species group	34	27	1	6	rest, grass, crop, urban, water, wet, heath, SVL	mber, pollin, carbon, recr, fish, w.qual, pest, erosion, a.qual
trees	12	9	1	2	rest, urban	mber, carbon, a.qual
pollinators	4	3	0	1	op, grass, forest, heath	ollin
fishes	2	1	0	1	ater	sh
Abundance of a species (functional) group	17	15	1	1	op, water, grass, forest, heath, trans, SVL, wet, coast	sh, pest, carbon, timber, pollin, w.qual, erosion
parasitoids	3	3	0	0	op	est
predators	3	3	0	0	op	est
macrophytes	2	2	0	0	et, water, trans	.qual
pollinators	2	2	0	0	op, grass	ollin
shrubs	2	2	0	0	ass, heath, crop, forest, SVL	arbon, erosion
Functional traits of a species group	8	5	3	0	rban, grass, forest, crop, SVL, water	.qual, carbon, fish, erosion, w.qual
traits of trees	5	2	3	0	rban, forest, crop, SVL	.qual, carbon, erosion
traits of herbs/grasses	2	2	0	0	ass	arbon, w.qual
Age of site / community	11	10	1	0	rest, heath, crop, grass, urban	arbon, erosion, timber, flood, recr
since abandonment	4	4	0	0	eath, crop, grass, forest	rosion, carbon
since fire	3	3	0	0	rest, crop, grass, heath	arbon, erosion
since cutting	2	2	0	0	rest	arbon, flood
Primary productivity	3	3	0	0	ater, grass	sh, carbon
Biomass at the site	30	22	1	7	rest, urban, grass, heath, wet, SVL, crop, water	.qual, carbon, flood, erosion, w.qual, fish, recr
belowground biomass	9	9	0	0	ass, forest, crop, heath, SVL	arbon, erosion, flood, w.qual
ground layer	6	4	1	1	ass, forest, crop, heath, SVL, wet	rosion, w.qual, carbon, flood
litter	4	2	1	1	ass, forest, heath, wet	.qual, carbon, flood
tree layer	4	2	0	2	rban, forest	.qual
Site structure	6	2	3	1	rest, wet, water, urban	mber, fish, flood, w.qual, recr, a.qual
Soil characteristics	4	1	1	2	op, forest, grass, heath, SVL	arbon, erosion, w.qual
Water availability / quality	11	9	1	1	et, water, crop, grass, urban, heath, trans	sh, flood, w.qual, carbon
washland	4	4	0	0	op, grass, wet, forest, heath	ood, fish
The extent of an ecosystem subtype	15	13	1	1	op, grass, urban	est, pollin, recr, w.qual
any seminatural feature (hedgerows, treerows, roadsides, oldfields)	13	11	1	1	op, grass, urban	est, pollin, recr, w.qual
The proximity of two different ecosystem types	10	9	1	0	op, water, urban, grass, forest, SVL	ollin, pest, flood, w.qual, fish, recr
Landscape diversity	10	9	0	1	op, grass, forest, heath, SVL, urban, wet, water	est, recr, fish, pollin, erosion
Management / disturbance intensity	28	5	22	1	rest, crop, grass, heath, urban, SVL, water, wet	ecr, erosion, pest, flood, pollin, timber, fish, carbon, w.qual
cutting regime	4	1	3	0	rest	mber, flood, recr
farming intensity	4	0	4	0	op	est, pollin, erosion
grazing intensity	3	1	1	1	ass	ollin, carbon, erosion
fire frequency	3	0	3	0	rest, crop, grass, heath, SVL	ood, erosion

** MAES ecosystem types: crop: cropland; grass: grassland; forest: woodland and forest; heath: heathland and scrub; SVL: sparsely vegetated land; wet: wetlands; water: rivers and lakes; trans: marine inlets and transitional waters*

*** Ecosystem services: timber: timber production; fish: freshwater fishing; pollin: pollination; pest: pest regulation; carbon: carbon sequestration; erosion: erosion protection; flood: flood protection; w.qual: water quality regulation; recr: recreation; a.qual: air quality regulation*

Beyond the three most relevant ones, several further groups of characteristics make considerable influence on specific ES in specific ecosystem types, so these characteristics should also be considered in a comprehensive set of ecosystem condition indicators. In fact, there are already many indicators available which can be linked to the various characteristics covered by the systematic review. This will be explored in the next chapter.

3.2 The selection of indicators

There are several considerations that potential indicators have to meet in order to characterize the condition of ecosystems in a way that is relevant both from an ecological and a policy perspective. Many of these considerations have already been mentioned in this document or in the fact sheets produced during this work (Table 1.1). In this chapter these considerations are brought together, to give a comprehensive overview on the criteria that need to underlie the assessment of ecosystem condition in a MAES context (Table 3.2). There are two types of considerations: some selection criteria affect individual indicators (by characterizing their relevance or usefulness), and some need to be applied to the whole set of candidate indicators (e.g. to ensure that there are no gaps or double counting).

Table 3.2: Selection criteria for ecosystem condition indicators

Criterion	Short description
Criteria for individual indicators	
Relevance	the selected characteristics (and their indicators) should be relevant in terms of influencing the ES capacity of the ecosystems for multiple ES
State orientation	the selected characteristics (and their indicators) should be interpreted as a state descriptor of the studied (socio-ecological) system
Framework conformity	the selected characteristics (and their indicators) should not be associated to any other 'box' of the MAES framework
Spatial consistency	indicators should be linked to a specific location (mapped)
Temporal consistency	indicators should be linked to a specific time period and sensitive to change
Feasibility	indicators should (potentially) be covered by data sources over large areas
Quantitativeness	indicators should be measured at a well-defined quantitative scale that allows comparisons
Reliability	primary (measured) data should be preferred to modelled /derived data
Normativity	indicators should preferably have an inherent 'normative' interpretation (reference direction / value / range)
Simplicity	indicators should be as simple as possible
Criteria for the whole set of indicators	
Parsimony	the set of indicators should cover as much information from the 'candidate variables' as possible with as few selected EC variables as possible
Data gaps	'topics' which seem to be relevant, but which are not covered adequately by available data sources should be highlighted as data gaps
Framework gaps	'topics' under the different framework boxes should be cross-checked, and 'no one should be left behind'

The criterion of **relevance** is perhaps the most important of all criteria, which is underlying the whole systematic review exercise described in this study. This criterion implies that the selected condition indicators should address those characteristics of the ecosystems, that are relevant in terms of ecosystem services. In fact, in line with the instrumental definition of condition discussed in Chapter 1.1, this criterion boils down to the selection of *those characteristics, which exert the most influence*

on the capacity of the ecosystems for providing multiple ES.[1] This 'ES footprint' of the candidate variables can offer an external anchor for the selection process. There are always too many potential condition variables, and practical considerations (discussed below under further criteria, e.g. *feasibility*, *framework conformity*, *reliability…*) alone do not guarantee that the eventual set of indicators will be meaningful in the context of a broader ecosystem service assessment / accounting exercise. Furthermore, as already emphasized in Chapter 1.1, well documented links between EC~ES can also help to communicate the importance of maintaining ecosystem condition using instrumental arguments.

The relatively abstract criterion of '**state orientation**' requires that condition indicators should describe the 'state' of the studied system as much as possible.[2] Most ecosystem characteristics don't have a single 'default' formulation (definition / indicator / quantification approach). If there is a choice between two alternative formulations, the more "state-like" formulation is generally the better. For example, in the case of ***pressures*** leading to degradation (depletion, accumulation) of environmental stocks, it is the stocks themselves that should be considered as condition variables instead of their change (degradation / depletion rates, fluxes, flows, or other indicators of flow intensity). Indicators describing policy interventions performed in ***response*** to degradation processes (e.g. the *share of N2000 areas*, or the share of *areas designated for specific management schemes*) don't make good condition indicators. In order to avoid confusions and double counting, indicators describing changes of stocks and policy should be avoided.

The criterion of **framework conformity** is of key importance for the integrity of the whole MAES assessment. According to this criterion, each aspect of the studied system should only be described under a single 'box' of the conceptual framework (Figure 1.1). Characteristics that can be better considered under *ecosystem extent* (e.g. SEBI 004, AEI 10.1, deforestation...) or *ecosystem service* (as ecosystem service indicators) should be handled there. If such characteristics are re-considered as condition indicators, that might lead to double counting and user confusion, and should be avoided as far as possible.

The criterion of **spatial consistency** means that the indicators need to be linked to a specific location (mapped). More specifically, all candidate variables have to be interpretable over *any area* which is (1) larger than a predefined minimum area ('*spatial grain*'), and (2) is covered by the one of the ecosystem types for which the variable makes sense ('*thematic domain*'). The grain and the thematic domain of each variable should be included in their definition. Ideally, the whole accounting should have a harmonized spatial grain, and the definition of the variables should respect this grain: for example a large grassland is handled as an ecosystem type, whereas a small ('sub-grain') grassland is considered as a part of the embedding ecosystem type (e.g. cropland) with the 'density' of such embedded fragments considered as a condition attribute of the embedding ET).

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[1] This requirement is also justifiable from a perspective of *systems science*, where the set of 'state' indicators of a system are expected to "describe enough about the system to determine its future behaviour" (Palm et al., 2010). As in the context of ES accounting / assessments the key output ("future behaviour") of the studied system is the portfolio of ES generated, it is important that the 'state variables' describing the system would capture everything that can influence this portfolio.

[2] Systems science, thermodynamics, and the DPSIR framework can also help to interpret this requirement. *System science* prescribes that state variables should be influential internal variables of the system (i.e. which determine future behaviour in the absence of external forces, Palm, 2010). *Thermodynamics* gives an operative guidance by distinguishing "intensive variables" (e.g. percentages, densities, concentrations) from "extensive variables" (e.g. absolute numbers, kilograms...), with intensive variables being considered to be more appropriate to describe state (more "state-like"). The *DPSIR framework* can add a further useful distinction, by delineating pressures (external influences/inputs on the studied system) and responses (conscious human adaptive behaviour, which is also considered external to the studied system) from state descriptors.

Temporal consistency implies that indicators are sensitive to change and linked to a specific time period. For several indicators with relatively fine temporal resolution (typically based on remote sensing data) the 'instantaneous' indicator values are too variable to be useful in a MAES context. A precise MAES definition of ecosystem condition should imply a specific 'temporal resolution/grain': a period that the indicators should characterize. Based on ecological considerations this grain should cover (once or multiple times) the most typical periodical cycle(s) which is a year. Socio-economic considerations (e.g. the need to be harmonized with accounting periods) also demand an annual (or multi-annual) grain from the MAES assessments. Sensitivity to change should also be considered with respect to this temporal grain, so that condition would be reasonably variable across a few time steps (i.e. *quasi-constant* or *extremely variable* candidate variables should be excluded or reformulated). This means that in such cases (e.g. NDVI, LAI, or NDWI-based indicators) the precise definition of the condition indicator should involve some sort of 'temporal aggregation', e.g. in the form of appropriate statistical aggregation functions (central tendencies or extremities, e.g. mean annual values, annual maxima, etc.).

Feasibility means that indicators should be covered by (potentially) available data sources over large areas. This implies that those characteristics that are difficult to measure, or are in any way unfeasible to be covered by data in the foreseeable future should be avoided.

According to the criterion of **quantitativeness** indicators should be measured at a well-defined quantitative scale, which allows for meaningful comparisons and change detection. Indicators should ideally be measured at a ratio scale or interval scale or at least at an ordinal scale (sensu Stevens, 1946). Attributes measured at a categorical/nominal scale should preferably not be used as condition variables, but they can be reformulated to an ordinal/interval/ratio scale (e.g. by using scores/weights, or by being quantified as the 'share' of a relevant subtype over a larger area).

The concept of **reliability** is linked to the uncertainties concerning the indicators. Good indicators should rely on data that are measured in an objective and standardized way. Primary (measured) data should in all cases be preferred to modelled /derived data, which always rely on a number of assumptions, contain inherent errors, and can thus be more easily criticized or disputed. Modelled data can change even retrospectively if the modelling technique is updated. In the formulation of the indicators, subjective elements should be avoided as much as possible, and if unavoidable (e.g. scores used for weighting 'components' of a composite indicator) they should rely on a broad consensus of 'experts' in a clearly documented way. Data streams should ideally be resistant to tampering/ manipulation.

Indicators should preferably have a straightforward '**normative**' interpretation, which can greatly improve its usefulness for policy practices and general communication. In simple words, an indicator should be able to distinguish what is 'good' from what is 'bad' – preferably in a consensual way. Ideally an increase in the variable should mean a better condition, and the same difference in the value should mean approximately the same 'difference in condition' at any part of the scale (i.e. there should be a 'linear' relationship between the variable and the underlying human value judgement). In the lack of clear linear and monotonous relationship *reference values* (or ranges) can help to establish normativity, and can also be used as a policy targets. In this case any deviation from the reference value can be seen as 'bad'. For example, the internal temperature of the human body can be seen as a key indicator of health, which meets the criterion of normativity, only if we define a reference value/range (37 +-0.5 °C). Any deviation from this range is a sign of illness. Finally, good indicators should be as **simple** as possible (but not any simpler). If every other criterion is ensured, simpler indicators (allowing easier policy interpretation and more powerful messages) should be preferred over more complex / abstract metrics.

The remaining three criteria do not focus so much on the characteristics of the individual indicators, but on the whole indicator set and the selection process. **Parsimony** means that the set of indicator

variables should be small without any unnecessary redundancies. In other words the final set of indicators should cover as much information as possible with as few indicators as possible. To this end the selected variables/classes should be independent / non-correlated as much as possible, but the set should still represent all major 'aspect' of the studied system (so that they could be rightfully considered as 'key indicators' of system state). Many times there can be correlations between seemingly unrelated variables, listed under different headings (age, biomass, biodiversity...) in the systematic review (Tables 3.1, 3.3 & 3.4). Correlations can indicate ecological relationships, or technical artefacts (e.g. by improper reuse of data streams), but they always imply high risks of confusions and losing credibility. In case of correlated indicators, the best (most relevant, most reliable, most framework-conform, simplest...) candidate should be chosen by careful considerations relying on the criteria for individual indicators.

And finally an ideal selection strategy for condition indicators should provide 'checklists' for verifying if a set is complete and comprehensive. Two types of 'fitness checks' can be distinguished here:

- those aspects (groups of characteristics) of the system, which seem to be relevant, but which are not covered adequately by available data sources should be highlighted as **data gaps**. The identification of such information gaps can help in guiding future research activities.

- an even broader thematic cross-checking can be made at the level of the whole MAES assessment, as there can be gaps and overlaps ('**framework gaps**') between the 'topics' addressed under the different parts of the assessment (or 'framework boxes' see Fig. 1.1). All relevant aspects of the studied socio-economic system should eventually be addressed in a *single* box of the framework (ecosystem extent, ecosystem condition, or ecosystem services), wherever it best fits. It is equally a mistake if a relevant aspect is present in multiple boxes ('double counting'), or it is entirely missing ('someone was left behind…')

As a final general consideration, the **role of pressures** in the condition framework should be revisited. In the MAES reports pressures are considered an "indirect approach" for measuring ecosystem condition (Erhard et al. 2016, p.31). However, the term "pressures" comprises a relatively broad range of processes, which interact with the studied ecosystems in highly different ways. Based on this, three types of pressures can be distinguished: As already mentioned above, many pressures (e.g. erosion, drainage/desiccation, fragmentation, pollution, etc.) can be associated to a state variable (e.g. soil thickness, water table level, connectivity, the concentration of specific pollutants, etc.) directly affected by the pressure and the underlying degradation process. In most cases there are indicators available for both the pressure (as a flux, flow or rate of change) and the underlying state variable (as a stock variable). It is recommended that in such cases **the stock variable underlying the pressure should be used as the condition indicator**. Using such characteristics as condition indicators comes with multiple advantages:

- the policy focus on pressures highlights the most endangered degradable stocks (state components) within ecosystems,
- which makes it possible to formulate clear and pertinent policy messages on ecosystem degradation (as a change in these environmental stocks),
- and as demonstrated by the systematic review, most of these stock variables directly influence the capacity of the ecosystems to supply various services.

The ability to indicate **degradation as a change** is a critical property of these environmental stocks as indicators. For some of these variables (soil thickness, water table level) there are no clear reference levels, thus it is difficult to use these condition indicators to formulate policy goals, and a single value at a particular location has only a limited normative meaning. Nevertheless, changes and trends still

have a very clear and direct interpretation, so these variables might still be considered policy relevant.

The underlying degradable stock variable is not equally well identifiable in the case of all 'pressure types' considered in the previous MAES reports (e.g. Maes et al., 2018). The pressure types distinguished involved habitat change, invasion, pollution, overexploitation, and climate change (often abbreviated as HIPOC classes using the initials).

- From the HIPOC pressure types ***pollution*** and ***invasion*** can be characterized by relatively straightforward state indicators: the concentration of the various pollutants (in soil, water, or air); and the abundance of invasive species (e.g. a specific species or an index summarizing multiple species).
- This is also true for ***habitat loss*** (where the degradable stock is the area / share of the ecosystem/habitat type in question), but as discussed above, this type of stock and its 'degradation' should generally be discussed under 'ecosystem extent' and should not be considered as condition. The only exceptions are processes 'internal' to a specific ecosystem type (e.g. soil sealing in the case of urban ecosystems), which can be characterized with their degradable stock (e.g. the share of impervious surfaces) as a condition indicator of the given ecosystem type.
- As the primary goal of any land use activity is the maximization of a target ecosystem service (typically a provisioning service), and most ES are interlinked through trade-offs, the intensity of management activities (***overexploitation***) is of key importance in an ES context. Management characteristics were perhaps the most studied group of variables in the primary scientific studies reviewed which exert a lot of well documented direct influence on services. If we consider *management* as a part of the studied system (n.b. several MAES types, e.g. urban and cropland, are uninterpretable without it), then their type and intensity becomes an internal component of the system, which can be seen as a valid system characteristic (just like a natural disturbance regime). This interpretation is fully compatible with the MAES framework, and in this way the most relevant aspects of human management regimes should be considered (and assessed) under the condition "chapter" of the EU MAES assessment.
- And finally, ***climate change*** is an inherently indirect pressure, without any corresponding degradable environmental stock. Nevertheless, climate change can induce other pressures, which can be reflected in the alteration of disturbance regimes (fires), or the indirect degradation of other stocks (water table levels, invasive species). Given also that climate is already very well covered with indicators and policy attention in other policy domains, it is proposed that climate change should not be addressed directly with MAES condition indicators.

Table 3.3: The most important potential ecosystem condition indicators, and their relevance for specific ecosystem types and ecosystem services based on the results of the systematic review, and an analysis of the condition indicators proposed in the 5th MAES report (Maes et al., 2018).

Indicator name	Ecosystem types (ET)[a]						Ecosystem services(ES)[a]					
	cro	gra	for	hea	SVL	wet	pol	pes	car	flo	w.q	rec
Biodiversity (diversity/abundance of major species groups)												
Conservation status and trends of species of community interest (for multiple ET) [SEBI 003]	1*	1*	1*	1*	1*	1*	1	1			2	2
Forest tree species (richness)			11	1	1		2	2	11			2
EU Population status and trends of bird species (%) [SEBI 003]	1*	1*	1*	1*	1*	1*	2	2				1
Bird indices (farmland, forest...) [SEBI 001]	11*	11*	11*	1	1	11	11	11	2			11
Grassland Butterfly Indicator [SEBI 001]	1	11		1	2	2	1	1				1
Conservation status and trends of habitats of community interest [SEBI 005]	1	1*	1*	1*	1*	1*	1	1				2
Deadwood [SEBI 018]			11*	2			2	1	2			2*
Ecological status of surface water bodies [SEBI 016]						11					11	11
Age of site / community												
Forest age (% of forest in age categories)			11	1					11	11		11
Community age (time since last major intervention/ disturbance: felling, fire, abandonment, etc)		1	2	11					11	1		2
Biomass at the site												
Normalized difference vegetation index (NDVI)		11	1	1	11	11			11	11	11	1
Biomass volume (growing stock) [SEBI 017]			11*	1					1	1	1	
Tree cover density	11	11	1	1	2				11	11	2	2
Soil characteristics												
Soil organic carbon (SOC)	11*	1*	1*	2	2				11		2	
Soil biodiversity (DNA-based richness)	11	1	1	1					2		1	
Soil thickness	1	1	1	1	11				11		2	
Water availability												
Water and wetness probability index (WWPI)	2			1		11			11	2*	1	2
Water availability (for agriculture)	1											
Washlands (regularly flooded areas)	2	1		2		11				11	1	
The extent (abundance) of a specific subtype (of the target ecosystem type)												
Extent of ETM subtypes [SEBI 004]	1	11	1	11	11	1	11	11	11	1	11	11
Extent of forest types			1						11	2		2
Density of embedded seminatural elements (hedgerows, lines of trees, etc.)	11	11				2	11	11	1	1	11	11
Tree cover density	11	11										
The coexistence / proximity of two different ecosystem types												
Proximity to (any) natural habitat	11						11	11				2
Proximity to water	1	1	1	1	1	1					11	11
Landscape diversity												
Landscape diversity	11	11	1	1	11	1	11	11		2	2	11
Landscape fragmentation & connectivity												
Landscape fragmentation from urban and transport infrastructure [LSI 004, CSI 054]	2*	2*	2*	2		2	2	2			2	2*
Fragmentation patterns of natural/seminatural landscapes [SEBI 013]		2	1*	1*		1*	1	1				2
Fragmentation patterns of forest landscapes [SEBI 013]			1*					2				
Forest connectivity [SEBI 013]			1*					2				

[a] Terrestrial MAES ecosystem types (cro: cropland; gra: grassland; for: woodland and forest; hea: heathland and shrub; SVL: sparsely vegetated land; wet: wetlands), and the studied ecosystem services (pol: pollination; pes: pest regulation; car: carbon sequestration; flo: flood protection; w.q: water quality regulation; rec: recreation) scored on the following scale:

- 11 *highly relevant for the specified ET or ES (highlighted as key indicator in the corresponding fact sheet)*
- 1 *relevant for the specified ET or ES*
- 2 *slightly relevant for the ET or ES*

** (in the ET columns): the indicators flagged as 'key indicator' in the 5th MAES report are highlighted with an asterisk(*) for each ecosystem type*

** (in the ES columns): most of the condition-service relationships are 'positive', i.e. a higher indicator value indicates better capacities for ES provision. 'Reverse cases' with a clearly negative relationship are flagged with an asterisk(*) in these columns.*

3.3 Indicators for ecosystem state (including biodiversity)

Table 3.2 reviews all non-pressure indicators that had been proposed as 'key indicator' in the 5th MAES report (Maes et al., 2018), or any of the fact sheets produced by ETC/BD in 2018 (Table 1.1). A longer and more detailed listing of all the indicators proposed by the 5th MAES report with a high amount of metadata can be found in Annex 1. In the following paragraph, these indicators are discussed, approximately following the groups of characteristics identified during the systematic review (Czúcz et al., 2017) in the order in which they appeared in Table 3.2.

The various aspects of **biodiversity** are perhaps the most relevant characteristics of the ecosystems determining their functioning, and thus capacity to provide various services. The most descriptors of biodiversity (abundance of species or species groups) are furthermore 'well-behaving' stock-like quantities with an easy direct policy interpretation. The operative applicability of biodiversity descriptors as ecosystem condition indicators is, however, seriously limited by data availability issues. The indicators based on *reporting obligations related to the key EU Nature directives*, which could be most relevant from a policy perspective, are unfortunately of a very low spatial resolution (Member States for the Birds Directive, and biogeographical regions nested in Member States for the Habitats Directive), and there are further data homogeneity issues related to the reporting practice of the Member States. Consequently, the related indicators are more appropriate for ecosystem accounting purposes (where spatial resolution is less of an issue) than MAES applications. There have been several attempts for increasing spatial resolution based on external data and predictive modelling, but following the principle of *reliability*, modelled data are not ideal for use as condition indicators. The best way of creating a limited number of meaningful indicators from the high number of reported species/habitats is aggregating them by ecosystem types (based on 'characteristic species'): this results in a set of three indicators (based on birds, other species, and habitats) for each ecosystem type. This list can be extended with an index characterizing wetland condition based on data on the *ecological status of surface water bodies* available from the Water Framework Directive (WFD) reporting scheme.

For a few specific taxonomic groups there are other data sources that might slightly improve the spatial resolution. The most significant databases contain bird records compiled from voluntary observations coordinated by the European Bird Census Council. Based on these datasets thematic bird indices (one for each ecosystem type, i.e. *farmland bird index*, *forest bird index*, etc.; SEBI 001) can be produced. Based on this dataset birds seem to be the only taxonomic group for which biodiversity indicators with a spatial resolution beyond NUTS2 (which can be considered the lowest threshold for 'spatial data' in an EU MAES context) can be reached based on existing data. For some parts of Western Europe butterflies also constitute a well-studied group, so in these countries a spatial refinement of the even coarser *grassland butterfly index* (SEBI 001) might be possible, but this is certainly not an option for all EU Member States. While it does not measure directly any species group, the amount of *deadwood* (SEBI 018) can be also seen as a biodiversity indicator, which characterizes the abundance of (microhabitats for) several key functional groups (insects, fungi) including a high number of endangered species. Although this indicator is currently only available at a very limited spatial resolution, the options for spatial refinement based on forestry data should also be investigated. And as a final option for characterizing local biodiversity in a spatially detailed, but thematically coarse way, a simple index roughly estimating the *naturalness* of each location can be relatively easily computed from the ecosystem type map underlying the whole MAES assessment (ETM v3.1, see later in the paragraph on subtypes).

Closely related to functional traits is the **age** of species and ecosystems, which can be a meaningful condition indicator for several ecosystem types, particularly forests. *Forest age* can be defined based on the age of the trees (the oldest cohort, or an average age), which can potentially be extracted from forest inventory data for whole Europe with a relatively good spatial detail. A slightly similar

concept of age can be extended to many further ecosystem types, where it can be defined as the time since the last major intervention/ disturbance event (typically abandonment). This concept of '*community age*' can be somewhat redundant with hemeroby. Such an indicator could potentially be defined for all (semi)natural ETs (and should be zero for agroecosystems and urban) on a remote sensing basis, but the feasibility of the idea should still be tested.

The amount of **biomass** is an important characteristic of ecosystems, constituting a major stock-like quantity tightly involved in their functioning. Biomass is organized into several compartments (aboveground / belowground biomass, canopy levels) and even some pools of non-living organic material (litter, *deadwood*) behave in many respects like biomass pools in the ecosystems. Pools are relatively difficult to measure directly, but the most relevant aboveground pools can be relatively cheaply and reliably characterized at a fine spatial resolution using remote sensing indicators (e.g. NDVI, or LAI). It is important to note that in order to achieve *temporal consistency* raw NDVI/LAI values (which are too variable) should be aggregated using appropriate (multi)annual statistics (e.g. mean annual values or annual maxima). As these indicators are meaningful for all ecosystem types, they should preferably be calculated 'wall to wall' (for the whole terrestrial area). This is also true for a potential *tree cover density* that can be particularly relevant for non-forest habitat types, including urban. Wood biomass, on the other hand, (*growing stock*, SEBI 017) is a key state indicator particularly designed for forests, which is based on a different data source (forest inventories). This gives it an added importance (inclusion of multiple independent data sources increases the reliability of the indicator set), but SEBI 017 is unfortunately only available at a very coarse spatial resolution as yet, so for maximum MAES utility a finer scale recalculation would be useful.

There are several ***environmental characteristics*** describing the major non-living components of ecosystems (soil, water, air…) which exert relevant influence on several ES. These characteristics were dispersed in several categories of the 'characteristics typology' of the systematic review (Czúcz et al., 2017), and consequently, they are dispersed in several sections in the tables ('Soil characteristics', 'Water availability', and 'Nutrient / material balances' in Tables 3.1, 3.3, 3.4 and Annex 1). The key **attributes of the soil** include *soil organic carbon* (SOC), *soil biodiversity* (DNA-based richness), and *soil thickness*, a newly proposed tentative simple 'state variable' that can be used to follow the progress of erosion. Unfortunately, for SOC sampling & database is primarily focussed at croplands, and there are even more data issues for soil biodiversity for which the number of sampling plots is still very limited, leading to a limited spatial resolution (or *reliability*, if the database is interpolated through modelling). Nevertheless, all of these indicators should ideally be computed wall to wall for all terrestrial ecosystems.

To characterise **water** in a terrestrial context, variables describing the availability of water (including its seasonality, extremities, etc.) seem to be the most important. The most accessible data source seems to be remote sensing: central tendencies or extremities of the normalized difference water index (NDWI) seem to offer a relatively reliable indicator(s) with a good spatial resolution. There are two further tentative new proposals for simple water availability indicators: a binary indicator (=polygon map) highlighting active floodplains (*washlands*), and a simple 'state variable' (*water table levels*) that could be used to follow the progress of drainage/desiccation in wetlands (if data sources are available). For wetlands indicators describing the chemical conditions of water (specific components from WFD 'chemical status') can also be used as a key environmental characteristic, closely related to the pressure of pollution. NDWI and washlands should ideally be computed wall to wall for all terrestrial ecosystems.

There are several further **stable abiotic environmental characteristics**, like climatic variables or geological factors, that strongly influence the functioning of ecosystems, but which don't change on human timescales (even if long-term indirect feedback is possible, e.g. *climate change*). Consequently, *climate* or *geology* (base rock, aquifers, etc.) are commonly not considered to be an

active part of ecosystems. Such characteristics were not considered during the systematic review, and they should preferably not be included among MAES ecosystem condition indicators, either.

The extent (abundance) of a specific **subtype** (of the target ecosystem type) also came out as an important category of ecosystem characteristics and condition indicators from this analysis. There are two major 'types' of subtypes to be considered here: ***habitat types*** which should be linked to a meaningful habitat classification system, and ***ecosystem fragments*** that could potentially be considered as a different ecosystem type, but as they are too small, they are still considered as parts of the embedding ecosystem. It is important to note, that technically any ecosystem characteristics can be considered as 'subtypes' (e.g. forest age categories, urban green, or 'washlands'). But these 'artificial subtypes' are most logical to be discussed with the characteristics they rely on, and this report follows this strategy in all other cases except for the two cases highlighted above (EUNIS subtypes, ecosystem fragments).

In the context of EU MAES ***habitat types*** should be best linked to the high level categories of the European Nature Information System (EUNIS), a harmonized European habitat classification system developed by EEA. On the European map of ecosystem types (ETM v3.1, Weiss & Banko, 2018) underlying the EU MAES assessment the level 2 categories of the EUNIS habitat typology are readily distinguished, and the reliability of this distinction is also provided. This is relatively meaningful in the case most ecosystem types, *except for forests*, where EUNIS level 2 categories seem not to be enough, and ideally at least three further (EUNIS level 3) subtypes should be distinguished under each category: *agricultural plantations*[3], *intensive plantations of alien species*, and *(semi)natural forests*. Land registers and forest inventories can provide additional data, which could help to clean up the mess caused by the contradictions in how between FAO, MAES and EUNIS forest definitions (see Czúcz 2018b for more detail).

There is one further major consideration, however, if habitat subtypes should be used as an ecosystem condition indicator: how to frame 'subtype membership' (a *qualitative* variable 'measured' at a *nominal scale* sensu Stevens, 1946) as a meaningful indicator that would match the criterion of *quantitativeness*. Even if the quantity (share) of specific types over a larger spatial unit is technically appropriate for being used as an indicator (cf. SEBI 004) or even in accounting tables; the high number of subtypes, and the relatively limited possibility for their 'normative' interpretation makes this type of indicators relatively inferior. Nevertheless, there is a relatively simple option for creating more meaningful indicators based on the subtypes (and potentially further categorical information available as maps): the subtypes can be characterized by scores reflecting type-specific 'mean values' of a specific characteristic. This strategy can work for a high number of characteristics (e.g. tree cover, water availability, etc.), but it works best for well-defined synthetic characteristics reflecting policy-relevant concepts, like *naturalness* or *hemeroby*, for which this may be the only efficient way to quantify them. It is important to note, however, that there is no point in defining a high number of indicators based on the subtype information as they will be correlated (*parsimony*). In the EU MAES condition assessment habitat subtypes should be preferably used to define a single hemeroby (or naturalness) indicator, which should preferably be calibrated with the involvement of expertise from all major institutions participating in the assessment (ENV, EEA, JRC, ETC/BD, ETC/ULS), resulting in a single indicator covering all ecosystem types (a wall to wall grid) reflecting a broad expert consensus about the naturalness / hemeroby of the ecosystem types.

[3] According to the European map of ecosystem types (ETM v3.1; Weiss & Banko, 2018) '*woodland and forest*' includes fruit trees; '*heathland and shrub*' includes vineyards and orchards of shrubs / smaller trees; and *grasslands* include permanent fields of herbaceous crops, as well as urban parks. A further potential anomaly to consider is the full extent of reedbeds (bogs, mires, etc.) with any amount of adjacent open water surface are considered as '*rivers and lakes*'; whereas the same habitats with no physical connection to open water were considered as *wetland*. (See more details in the fact sheets dedicated to specific ecosystem types: Czúcz, 2018a-c.)

The other 'type' of subtypes, ***ecosystem fragments***, can be considered in the case of all ecosystem types (e.g. forest clearings), but they are most relevant in the case of artificial ecosystem types (i.e. croplands, but potentially also orchards, plantations, or intensively managed grasslands). In the case of croplands (and also urban ecosystems, which are not discussed in detail here), the presence / abundance of seminatural vegetation in the embedding ecosystem type is one of the most critical factors determining the supply of a broad range of ecosystem services. The *density of embedded seminatural elements* (hedgerows, lines of trees, etc.) in croplands can be characterized with JRC's *seminat* database (Garcia-Feced et al., 2015). There is a slightly similar JRC data product (Paracchini et al., 2008), which delineates *high nature value* (HNV) farmlands as polygons (i.e. a 'subtype' of agricultural land). Nevertheless, the way how HNV farmlands are currently calculated also involves 'response indicators' (e.g. Natura 2000 and IBA designations) and Natura 2000 reporting data. Beyond breaking the principle of 'state orientation', this also creates correlation with biodiversity indicators based on the same data stream, thus the *density of seminatural elements* can be seen as superior to HNV for this purpose.

The spatial configuration of various ecosystem types at the landscape level has a major influence on the supply of several ecosystem services. In the simplest case it is the physical contact (or **proximity**) of two different ecosystem types that is necessary for an ES to be delivered. There are two relevant cases: (1) pollination and pest control necessitates that croplands be surrounded by (semi)natural habitats, whereas the physical connection of wetlands to water (i.e. rivers and lakes) is important for water quality regulation, and the same variable (*proximity to water*) is highly relevant for recreation in the case of any natural ecosystem type (having 'natural green' next to open water makes a landscape appealing). Nevertheless, these proximity relationships are challenging to be captured as a neat ecosystem condition indicator as interpreting 'average proximity' can be challenging to policy makers (e.g. there are no inherent normative interpretations or reference values for 'proximity').

Landscape diversity can offer a related, but slightly easier to interpret indicator(s). Both proximity indicators and landscape diversity are new proposals, but on the basis of ETM v3.1 they can be relatively easily implemented as practical 'wall-to-wall' indicators (e.g. landscape diversity as the local Shannon diversity of relevant ecosystem types calculated with a moving window).

The **fragmentation** and/or the **connectivity** of the landscape also determine its quality for a high number of species, and thus influence ecological processes and ecosystem services. There is no need to have both fragmentation and connectivity in the final set of indicators, as they are complementary (thus correlated and redundant) concepts: the more fragmented a landscape is, the less connectivity it has. The most widespread fragmentation metric (effective mesh size) even uses the 'probability of being connected' to measure fragmentation. Nevertheless, both fragmentation and connectivity calculations rely on an underlying distinction between 'good' (permeable) and 'bad' (hostile, impermeable) habitat types often called 'fragmentation geometry' in the software tools dedicated to calculating such indicators; and this fragmentation geometry aspect of the calculations is much more crucial in terms of the usefulness of the resulting index, than the choice of the metric itself. The best choice for fragmentation geometry is a distinction that is relevant for the broadest range of natural species. Unfortunately, the recent EEA '*fragmentation from urban and transport infrastructure*' indicator (LSI 004 / CSI 054) considers intensive agriculture as permeable (='good' for nature). This is not the case for most of the threatened species in Europe, as well as many functionally relevant species groups (plants, many natural enemies, soil biodiversity). A more relevant distinction could be made between (semi)natural and anthropogenic ecosystem types, thus a fragmentation/connectivity index that considers the latter (urban, cropland, and perhaps the anthropogenic subtypes of forest and heathlands (orchards, berry plantations)) as 'barrier', can be relevant for most of the natural species. The '*fragmentation patterns of natural/seminatural landscapes*' is also available already as a SEBI indicator (SEBI 013), but for timeliness and consistency, it should probably be recalculated based on ETM v3.1 (possibly reusing the script developed for the

LSI 004 indicator). This way a single fragmentation/connectivity index could be enough for the whole MAES condition assessment.

There are also a few further topics (groups of characteristics) that were covered by the systematic review, but for which there are no indicators in Table 3.3. **Functional traits** (including tree phenology and leaf-related traits) were highlighted by the forest pilot as relevant, and in fact, they were found to influence some services (e.g. air quality regulation) in the literature review. Similarly, aggregate metrics describing **ecosystem functioning** (e.g. primary productivity) are also clearly relevant for several ES. The key issue is *feasibility* in both cases: there are relatively few data available at a scale relevant for EU MAES (traits), and the ones that are available are modelled data, with inherent *reliability* issues (functioning). A further issue with ecosystem functioning indicators is that in many cases they should rather be considered as service indicators (typically of regulating ES), instead of condition indicators (*framework conformity*). Nevertheless, both traits and functioning are inherently connected (correlated) with other characteristics of the ecosystems, so there are, in fact, several indicators in Table 3.3 which can also be considered as 'functional indicators' (e.g. NDVI for *primary productivity*, deadwood for *decomposition*, or soil organic carbon for *soil fertility*).

3.4 Indicators for pressures (management / disturbance intensity)

Table 3.4 reviews all the pressure-related indicators that had been proposed as 'key indicator' in the 5th MAES report (Maes et al., 2018), or any of the fact sheets produced by ETC/BD in 2018 (Table 1). A longer and more detailed listing all of the indicators proposed by the 5th MAES report with a high amount of metadata can be found in Annex 1. In the following paragraph, these indicators are discussed, according to the groups of characteristics identified during the systematic review (following dominant land uses and disturbance processes, see Czúcz et al., 2017) in the order in which they appeared in Table 3.4.

There are few options to characterize the intensity of the human use of the ecosystems in a very general way, the most accessible way being a **general hemeroby** indicator. Ecosystem types (and subtypes) can be assigned a 'hemeroby' score, which indicates the level to which they are transformed by human use (Walz & Stein, 2014), thus constituting a relevant wall to wall indicator (which is the opposite of '*naturalness*' and has already been discussed in the paragraph on ecosystem subtype indicators).

The **management of croplands** includes a high number of complex activities, so the intensity of cropland management can be characterised from a broad range of aspects, which are though slightly correlated. There is ample evidence that the various aspects of management (pesticide use, crop types, organic vs conventional system, etc.) influence a broad range of services even beyond the agricultural fields, but there is relatively little data available on the actual management regimes, that could be used as indicators. The '*intensification / extensification*' (AEI12) of the production system can be considered as a relatively general key indicator, which relies on field data from an EU wide farm network, but which is only available at a regional (NUTS2) level. The *share of organic farming* systems (SEBI 020, AEI4) and *fallow land* are slightly related indicators, with disparate policy messages.

Grasslands are typically used for grazing or hay (fodder) making so *livestock density* can be a primary indicator of grassland use intensity. Nevertheless, it would be important to correct this indicator for non-grassland-based fodder inputs (making it a 'net/grazing livestock density'). The resulting indicator could be turned into a wall to wall map, as the grazing pressures can be meaningful for the whole landscape, not only the grasslands.

There are several options to characterize the **intensity of forest use**. The *long term ratio of annual fellings to net annual increment* (SEBI 017) is a key indicator of forest (use) sustainability, but the mere *length of the felling cycle*, a 'disturbance frequency' style simple indicator, could also be considered as a slightly different simple indicator, which is more relevant for many ES. Game animals and hunting is a different aspect of forest use, which is, however, relevant for the entire landscape. *Game density* (or its ratio to sustainable levels) with appropriate 'gamestock units' could be a meaningful wall to wall indicator characterizing this pressure – hopefully this is feasible based on official game statistics.

For **urban** ecosystems *soil sealing* can be seen as a key pressure, with *imperviousness* (=the share of sealed surfaces) as an underlying 'degradable environmental stock' variable, the changes of which clearly reflect the process of soil sealing. The EU Copernicus programme delivers a regularly updated fine resolution map of imperviousness for European cities, which can thus be highly relevant as a key urban condition indicator for the EU MAES assessment.

Table 3.4: The most important potential ecosystem condition indicators, and their relevance for specific ecosystem types and ecosystem services based on the results of the systematic review, and an analysis of the condition indicators proposed in the 5th MAES report (Maes et al., 2018).

Indicator name	Ecosystem types (ET)[a]						Ecosystem services (ES)[a]					
	cro	gra	for	hea	SVL	wet	pol	pes	car	flo	w.q	rec
All ecosystems and land uses												
Hemeroby	11	1	11	11		1	11	11	2	2	2	11
Farming intensity												
Intensification / extensification [AEI12]	11*	11*		2		2	11	11	2	2	11	1
Share of organic farming [SEBI 020, AEI4]	11*	2*				2	1	11	2		2	
Share of fallow land	11						11	11	2	2		2*
Grazing intensity												
Livestock density	2*	11*		1	1	2	11	1	2*	2	2	1*
Forest use intensity												
Long term ratio of annual fellings to net annual increment [SEBI 017]			11*	2			2	2	11	1		2
Length of the felling cycle			11	2			2	2	1	11		1
Game density (or ratio to sustainable levels)			11	2	1				2			1*
Nutrient / material balances												
Gross nitrogen balance [~SEBI 019, AEI15]	11*	1*	2	11		11	2	2	2		11	
Critical load exceedance for nitrogen [SEBI 009]	1	2	2	1*		1	2	2	2			
Gross phosphorus balance [AEI16]	1*	2*	2	2		11	2	2	2		1	2
Chemical status of surface/ground water [SEBI 016]	11	1	2	11		11	2	2	2		11	11
Tropospheric ozone concentration [IND-30, CSI 005, AIR 004]	2		1*						2			
Soil loss												
Loss of organic matter	2*	2*		2	2				1		2	
Imperviousness	2								2	11	11	11
Fire regime												
Number of fires	2	2	11	11	11				11	11		2

[a] Terrestrial MAES ecosystem types (cro: cropland; gra: grassland; for: woodland and forest; hea: heathland and shrub; SVL: sparsely vegetated land; wet: wetlands), and the studied ecosystem services (pol: pollination; pes: pest regulation; car: carbon sequestration; flo: flood protection; w.q: water quality regulation; rec: recreation) scored on the following scale:

- 11 *highly relevant for the specified ET or ES (highlighted as key indicator in the corresponding fact sheet)*
- 1 *relevant for the specified ET or ES*
- 2 *slightly relevant for the ET or ES*

** (in the ET columns): the indicators flagged as 'key indicator' in the 5th MAES report are highlighted with an asterisk(*) for each ecosystem type*
** (in the ES columns): in most cases indicator values standing for a lower pressure (use/disturbance) intensity indicate better capacities for ES provision. 'Reverse cases' where higher pressures come with higher ES supply are flagged with an asterisk(*) in these columns.*

Pollution and nutrient inputs constitute a major pressure that cannot be strictly bound to any specific ecosystem type. Nitrogen (N) and phosphorus (P) are two macronutrients that seem to play a key role, and there are several potential indicators based on various data sources available for both (especially N). For the fluxes (rate of pollution) *gross balances* (AEI 15, AEI16) seem to be the best available indicators, though for P the spatial resolution is very coarse, and for N the indicator is

partly based on modelling, neither of which are favourable for a MAES condition indicator. A perhaps better option is to assess the state of the ecosystems with respect to this 'degrading' process, and to characterize pollution with levels of 'pollutedness'. The *chemical status of surface and groundwaters* (especially N concentration levels) from the WFD reporting schemes seem to be a highly relevant and readily accessible indicator for this purpose.

From the various natural disturbances that ecosystems must face fires seem to be the most relevant, as the frequency / intensity of wildfires influences several ecosystem services according to the results of the systematic review. Perhaps the best indicator that can be defined here is the frequency of fires, which can be reliably built based on remote sensing data actively monitored by the JRC. As fires pertain to all terrestrial ecosystem types, this indicator should also be wall to wall.

4. Conclusions

In 2017 and 2018 the European Topic Centre for Biological Diversity (ETC/BD) worked on exploring functional relationships between ecosystem condition and ecosystem services (ES), based on a **systematic review** of scientific studies (100 scientific studies for 10 different ES). This exercise has led to the creation of a series of fact sheets (see Table 1.1), which explore the ways **how *ecosystem condition* can be meaningfully defined and measured in the studied ecosystem types**.

Based on the results of this systematic review there are three broad groups of ecosystem characteristics of key importance in terms of their influence on ecosystem services (see Fig. 3.2):

- the **(bio)diversity** of the ecosystems,
- the mass of living matter (**biomass**) accumulated, and
- the intensity of human or natural **disturbances** and **management** activities.

Furthermore, **13 criteria** were identified (see Table 3.2), which can support the process of selecting concrete condition indicators for these characteristics. The characteristics were then matched to the condition indicators proposed by the EU MAES pilots, and the relevance of each indicator was evaluated (Tables 3.3. & 3.4).

The inclusion of **pressures** into an ecosystem condition assessment has long been a controversial topic. With respect to this question the following main recommendations were made:

- If there is a **state variable** (a 'degradable stock') which can be associated to the pressure in question, then this state variable should be used as the condition indicator. (E.g. the state of *imperviousness* should characterize the process of *soil sealing*; or the *concentrations of specific pollutants* should stand for the various *pollution* processes).
- Otherwise, if possible, the pressure should be assessed with a **management intensity** indicator (which contains relevant information, no matter if it is considered to be part of ecosystem condition, or not; e.g. grazing intensity should be assessed for grasslands).
- If this is not possible then the pressure should not be directly considered in the context of the condition assessment. (E.g. slope, aspect, climate, or accessibility should not be considered directly as ecosystem condition – however if climate change will cause changes in other condition variables then its impacts will be considered anyway.)

For all of the major ecosystem types several potential indicators have been identified in Tables 3.3. and 3.4 with varying degrees of relevance and feasibility. As there are still many overlaps and redundancies in this list, Table 4.1 provides *a tentative "shortlist" of relevant indicators* for the EU MAES condition assessment. The main purpose of Table 4.1 is to be a source of inspiration for the EU MAES assessment, and it does not mean to be the least prescriptive in any sense. The main connections between ecosystem types, ecosystem condition indicators, and ecosystem services are further illustrated with a network diagram in Figure 4.1.

Table 4.1 and Figure 4.1 only cover the terrestrial ecosystem types, so there are no indicators proposed for freshwater and marine ecosystems. The indicators are grouped in a way that is similar to the way how indicators are grouped in the 5th MAES report (Maes et al., 2018); as this grouping structure (biotic state, abiotic state...) may facilitate subsequent aggregation in a meaningful and policy-relevant way. There are two main types of indicators in Table 4.1:

Table 4.1: A tentative minimal set of condition indicators to assess the condition of *terrestrial* ecosystem types based on the 5th MAES report (Maes et al., 2018). All of the proposed condition indicators influence multiple ES as documented by the systematic review.

Indicator name	Ecosystem types*	Ecosystem services**	Comments
Biotic state			
Species diversity			
Conservation status of species of community interest [SEBI 003]	**all**	poll, pest, w.qual	*Multiple indicators (one for each ET), only available at a very coarse spatial resolution, still very important because of its comprehensivity and direct policy links*
Bird indices (farmland, forest...) [SEBI 001]	**all**	poll, pest, recr	*The most accessible biodiversity indicator (probably the only one which can be refined to a spatial resolution beyond NUTS2 based on existing data), can produce (multiple) "wall-to-wall" map(s)*
Ecological status of surface water bodies [SEBI 016]	wetland	w.qual, recr, fish	*Multiple indicators (individual components could be considered instead of the overall score)*
Ecosystem structure			
Normalized difference vegetation index (NDVI)	**all**	carbon, flood, w.qual, recr, erosion, a.qual	*Instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators, appropriate statistics (e.g. mean annual values and extremities) should be calculated wall-to-wall; in urban ecosystems this can be a simple proxy for urban green*
Density of embedded seminatural elements	cropland (grassland)	poll, pest, w.qual, recr	*The density of seminatural ecosystem fragments (hedgerows, lines of trees, etc.) in transformed ecosystem types (cropland, grassland); these elements are seen as parts of the embedding ecosystem type*
Forest age	forest	carbon, flood, recr, erosion, timber	*Based on forest inventories, needs to be developed (e.g. as % of old trees)*
Abiotic state			
Soil			
Soil organic carbon (SOC)	**all**	carbon, flood, erosion, timb.	*Could be improved (sampling & database is primarily focused on croplands); can be seen as the 'degradable stock' behind erosion / soil degradation*
Imperviousness	urban	flood, w.qual, recr	*Can be seen as the 'degradable stock' behind soil sealing, can be correlated with biomass (NDVI) in cities*
Water			
Chemical status of groundwater [SEBI 016]	**all**	w.qual, fish	*Multiple indicators (individual components could be considered instead of the overall score), can be seen as the 'degradable stock' behind pollution processes, relevant for all terrestrial ecosystem types*
Chemical status of surface water [SEBI 016]	wetland	w.qual, recr, fish	*Multiple indicators (individual components could be considered instead of the overall score), can be seen as the 'degradable stock' behind pollution processes, relevant for wetlands (and freshwater/ marine, which is not discussed here)*
Water and wetness probability index (WWPI)	wetland	carbon, w.qual	*A simple remote sensing based wall-to-wall wetness index, relevant for wetlands (could even be used for their delineation on ETM), can be seen as the degradable stock behind their desiccation/ drainage*
Management / disturbance intensity			
Number of fires	**all**	carbon, flood, erosion, timber	*A major pressure with a reliable remote sensing data source, relevant for almost all terrestrial ETS, should be wall to wall*
Agricultural intensity ("intensification / extensification" [AEI12])	cropland (grassland)	poll, pest, w.qual, recr, erosion	*Only available at NUTS2 level, the name (and content) might need to be adjusted to better reflect the underlying state variable (i.e. intensity (which is a state) instead of intensification (which is a process))*
Livestock density	grassland	poll, pest, recr, erosion	*Would be great to correct for non-grassland-based fodder inputs (a 'net/grazing livestock density'?)*
Landscape integrity			
Landscape diversity	**all**	poll, pest, recr, erosion	*Can be relatively easily developed based on ETM v3.1*
Connectivity of (semi)natural ecosystems [SEBI 013]	**all**	poll, pest	*Could be (re)calculated using ETM v3.1 with a fragmentation geometry distinguishing (semi)natural ecosystems from transformed land (urban incl. major roads, and cropland incl. intensive plantations (classed under forest/shrubland in ETM v3.1)); can be seen as the 'degradable stock' behind the process of fragmentation*
Hemeroby / naturalness	**all**	poll, pest, recr	*A simple integrative quality score assigned to each (sub)type of ETM v3.1 in a consensus scoring exercise, a simple integrative 'indicator' with a long history*

** Crosscutting indicators (i.e. indicators which could be calculated 'wall to wall' for all terrestrial ETs) are highlighted in **bold**.* [a] *More details about the relevance of each indicator in the specific ecosystem types and for each ES can be found in Tables 3.3, 3.4 and technical metadata of each indicator are given in Annex 1.*

*** Ecosystem services: timber: timber production; fish: freshwater fishing; pollin: pollination; pest: pest regulation; carbon: carbon sequestration; erosion: erosion protection; flood: flood protection; w.qual: water quality regulation; recr: recreation; a.qual: air quality regulation*

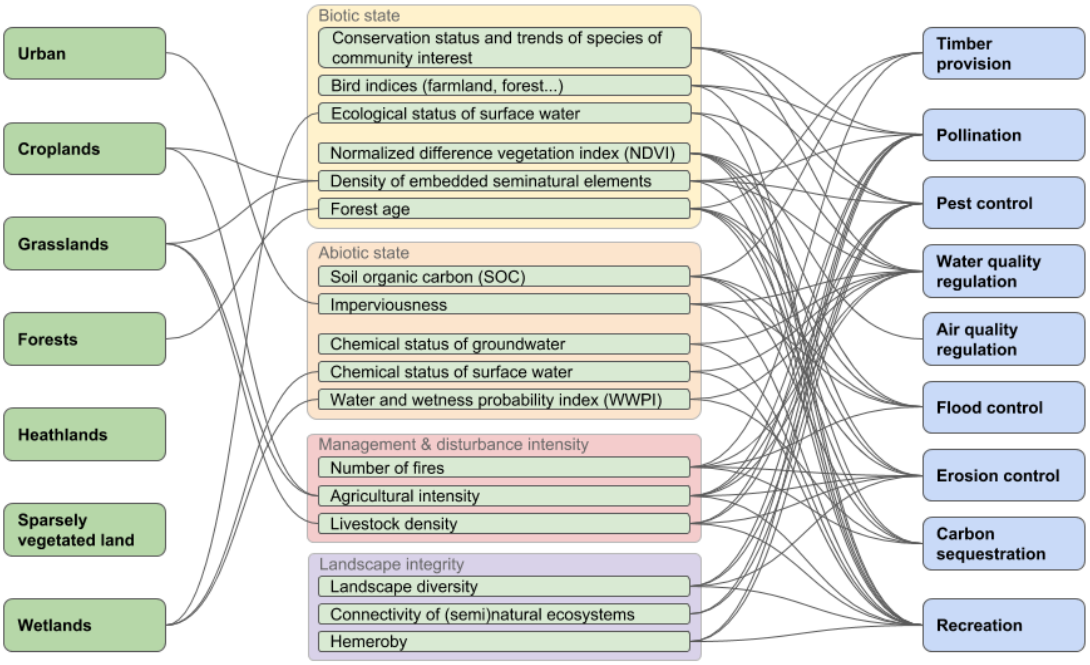

Figure 4.1: Synthesis of links between ecosystem types, ecosystem condition indicators, and the ecosystem services they influence. Crosscutting indicators are highlighted in *italics*, to reduce the number of lines these indicators are not connected to the individual ecosystem types in the left part of the figure. On the right side, the EC~ES connections are drawn based on the systematic review and the gap analysis. Similar network diagrams for the individual ETs and ESs can be found in the individual fact sheets (see Table 1.1).

- **cross-cutting** indicators, which can be calculated for all terrestrial ecosystem types; and
- **thematic** indicators, that are only relevant for a specific ecosystem type.

Cross-cutting indicators can be considered particularly valuable for the EU MAES assessment, as they provide relevant condition information for all ecosystem types. All groups of indicators contain one or more cross-cutting indicators, as well as one or more thematic indicators (with the exception of the group "landscape integrity" which only contain cross-cutting indicators). The final specification of these indicators should be done in cooperation with the various thematic expert group ('ecosystem pilots'), and ES modeller communities who will contribute to the EU MAES assessment, thus ensuring maximal consistency between the various layers of the assessment. The main intention of this report (and the accompanying fact sheets) is to contribute to this process as far as possible.

The links identified between ecosystem condition and services can provide solid and objective arguments for the conservation / restoration of ecosystems. This way this analysis can contribute to the implementation of further European and global biodiversity targets, and can support the mainstreaming of biodiversity into further policy domains.

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Annex 1: Annotated list of potential MAES ecosystem condition indicators

The table in this Annex lists all indicators that have been proposed for application as condition indicators in the context of the EU MAES assessment. All indicators were scored according to the following two general aspects of 'usefulness':

- **rep**: the degree to which the indicator represents the underlying indicandum (=the characteristic which it aims to address) [1: good representation (e.g. indicator fully covers a major aspect); 2: partial representation; 3: poor representation].
- **ava**: availability of indicator [1: available with a good quality & spatial resolution (at least NUTS2) for most of the EU (might still need some feasible update); 2: there is something available (but needs more work); 3: still to be developed (or needs major enhancements))].

Representativeness (rep), and availability (ava) are highlighted with a traffic lights colour scheme (following that of the 2nd MAES report, Maes et al., 2014). The remaining columns contain the following informations / metadata:

- **HI**: link to the HIPOC categories (just for pressures! – H: habitat loss, I: invasion, P: pollution, O: overexploitation, C: climate change);
- **indi.set**: link to high-level European indicator sets, if relevant (SEBI: Streamlining European Biodiversity Indicators, AEI: Agri-Environmental Indicators);
- **source**: the name of the data source / host institution, complemented with a weblink reference to a good description of the indicator where available;
- **unit**: the unit of the indicator;
- **pilot**: a list of previous studies (mainly MAES pilots: Maes et al., 2018) that had mentioned/proposed the indicator before (a: agroecosystems pilot; f: forest pilot; n: nature pilot);
- **date**: the reference period / years for which values of the indicator are available;
- **s.resol**: spatial resolution of the already available values of the indicator;
- **s.cover**: spatial coverage of the already available values of the indicator.

Unimplemented indicators (indicators under development) are highlighted in grey text, indicator families (which can/should be customized to the specific ecosystem types) are highlighted in *italics*, whereas the names of newly proposed indicators for filling gaps are highlighted in **bold**. The spatial resolution of indicators that don't reach the expected level of detail (at least NUTS2 region) is also highlighted in **bold**.

HI	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
			Biodiversity (diversity/abundance of major species groups)							
			species in general							
	1	2	*Conservation status and trends of species of community interest (for multiple ET)*	SEBI 003	Art17 DB	%	afn	2013, 2018	**MS x BGR**	EU
	1	2	*Red List Index of threatened species*	SEBI 002	EEA, IUCN	index	afn	1980s 2004,...?	**EU (MS?)**	EEA39

HI	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	2	2	Living Planet Index for Mediterranean wetlands		WWF	index	n	1970-2005	**MS**	Mediterr countries
	?	?	Community Specialisation Index		ETC/ ULS?	index	n	?	?	?
	1	2	Invasive alien species (richness)	SEBI 010	JRC-EASIN	1/area	f	?	10km	EU+
	1	3	Species diversity, richness (number and abundance of species, including vascular plants, vertebrates, etc)			index	f	?	?	?
			plants							
	3	3	Plant functional types (diversity)			?	f	?	?	?
	2	2	Forest tree species (richness)		AFOLU, MS?	1/area	f	~1998	100m	EU28, BY, MD
	3	3	Understory vegetation (richness)			1/area	f	?	?	?
	3	3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)			?	f	?	?	?
	2	3	Phylogenetic diversity			index	f	?	?	?
			birds							
	2	2	EU Population status and trends of bird species (%)	SEBI 003	Art12 DB	index	afn	2013, 2018	**MS**	EU
	2	1	*Bird indices (farmland, forest...)*	SEBI 001	EBCC	index	afn	2002-	**MS**	EU
			insects							
	2	2	Grassland Butterfly Indicator	SEBI 001	EEA	index	a	1990-2015	**MS**	22 MS
	2	3	Wild pollinators (richness, abundance, or diversity)			?	a	?	?	?
	2	3	Rove and ground beetles (richness)			1/area	f	?	?	?
			habitats							
	1	2	*Conservation status and trends of habitats of community interest*	SEBI 005	Art17 DB	%	afn	2013, 2018	**MS x BGR**	EU
	2	2	*Threatened habitat cover*		Art17 DB	%	fn	2013, 2018	**MS x BGR**	EU
	2	2	Deadwood	SEBI 018	EEA	m3/ha	f	2000-2010	**MS**	25 from EEA39
	1	1	Naturalness (index or typology)			index	f	?	?	?
	2	2	Red List Index of threatened habitats		IUCN EU RL	index	f	2017	?	?
	1	1	*Ecological status of surface water bodies*	SEBI 016	WISE	index		1992-	RBMP	EU
			Functional characteristics (traits) of major species groups							
	3	3	Leaf phenology type, leaf age, leaf development (measures according to annual cycles)			?	f			
	2	3	Plant and canopy phenology (measures according to annual cycles)			?	f			
	3	3	Greening response (remote sensing proxies)			?	f			
	2	3	Defoliation			% of trees	f			
	3	3	Discolouration			% of trees	f			

HI	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	3	3	Leaf-related indicators			?	f			
			Age of site / community							
	2	2	Forest age (% of forest in age categories)		JRC, MS?	% or y	f	?	?	?
	1	3	**Community age (time since last major intervention/ disturbance: felling, fire, abandonment, etc)**		?	y		?	?	?
			Primary productivity (& ecosystem exchange processes)							
	1	1	Plant productivity (NPP)		MODIS	t/ha/y	f	2000-	500m	Global
	2	1	Crop gross primary production		Agri4cast; CAPRI	t/ha/y	a	1995-2015	25km; HSU	EU28
	2	1	Carbon sequestration (Dry matter productivity)		Copernicus	t/ha/y	f	2014-	300m	Global
	2	3	Carbon dioxide exchange and carbon balance (net ecosystem–atmosphere CO2 exchange)			t/ha/y	f			
	3	3	Leaf respiration (net ecosystem–atmosphere CO2 exchange)			t/ha/y	f			
	2	1	Evapotranspiration		ECA&D	m3/ha/y	f	1950-	~25km	Europe
			Biomass at the site							
	1	1	Normalized difference vegetation index (NDVI)		Copernicus	index	f	1998-	1km	Global
	1	1	Leaf Area Index (LAI)		Copernicus	index	f	1998-	1km	Global
	2	2	Biomass volume (growing stock)	SEBI 017	EEA	m3/ha	f	1990-2010	**MS**	EEA39
	2	2	Carbon stock		FAO-FRA	t/ha	f	1990-2015	**MS**	Global
	1	2	Tree height		JRC, MS?	m	f	?	?	?
	1	2	Tree cover density		JRC, MS?, Copernicus?	%	f	?	?	?
	3	3	Tree crown size (diameter)		JRC, MS?, Copernicus?	m	f	?	?	?
	3	3	Canopy volume (from remote sensing)		JRC, Copernicus?	m3	f	?	?	?
			Site structure							
	1	1	Structural heterogeneity		JRC	index	f	2006	250m	EU27
	1	3	Structural heterogeneity index (from remote sensing)			index	f			
	1	3	Structural homogeneity index (from remote sensing)			index	f			
			Soil characteristics							
	2	2	C/N ratio in soil		IMAP, LRTAP	%	f	2005	5km	EU
	1	1	Soil organic carbon (SOC)		LUCAS	% or g/kg	afn	2009, 2015	1km	EU25, EU28
	2	1	Soil pH		LUCAS	pH	af	2009, 2015	1km	EU25, EU28
	3	2	Soil erodibility (K-factor)			t ha h / ha MJ mm	afn		500m?	EU25?
	3	1	Bulk density			kg/m3	afn	2018	1km	EU28

HI	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	1	3	Soil biodiversity (DNA-based richness)		LUCAS	1/area	afn	2018		EU28
	2	1	Soil nutrients availability (nitrogen & phosphorus)		LUCAS	mg/kg	afn	2009, 2015	1km?	EU25, EU28
	1	1	**Soil thickness**		LUCAS?	cm		?	?	?
			Water availability							
	1	1	**Water and wetness probability index (WWPI)**		Copernicus	%		2009-	100m	EEA39
	1	1	**Normalized difference water index (NDWI)**		JRC	index		?	1km	Europe
	1	2	Soil moisture (summer water stress)	IND-201, LSI 007	EEA, ECMWF	index	afn	1951-	25km?	EU28?
	2	2	Available water capacity (index)			index	afn			
	2	2	Water availability (for agriculture)		ETC/ACC	m3/ha/y	a			
	1	3	**Water levels**		?	?		?	?	?
	1	2	**Washlands (regularly flooded areas)**		ETM, DEM, ?	binary		2012	?	?
			The extent (abundance) of a specific subtype (of the target ecosystem type)							
	1	1	Extent of ETM subtypes	SEBI 004	CLC	%		1985-	100m	EU27
	1	3	Extent of forest types		forest inventories?	%	f			
	1	1	Density of embedded seminatural elements (hedgerows, lines of trees, etc.)		JRC	%	a	2006	1km	EU27
	1	1	HNV area		JRC	%	a	2000, 2006	100m	EU27
	1	3	Tree cover density		JRC, MS?, Copernicus?	%	f	?	?	?
	2	3	**Extent of regularly flooded land ("washland")**			%				
			The coexistence / proximity of two different ecosystem types							
	1	1	**Proximity to (any) natural habitat**		ETM	km (or m)		2012-	?	EU28+, TR, W. Balkan
	2	1	**Proximity to forests**		ETM	km (or m)		2012	?	EU28+, TR, W. Balkan
	2	1	**Proximity to wetlands**		ETM	km (or m)		2012	?	EU28+, TR, W. Balkan
	2	1	**Proximity to water**		ETM	km (or m)		2012	?	EU28+, TR, W. Balkan
			Landscape diversity							
	1	1	**Landscape diversity**		ETM	index		2012	?	EU28+, TR, W. Balkan
	?	1	Landscape abandonment		ETC/SIA ??	index	n	2014	?	?
			Landscape fragmentation & connectivity							
	1	2	Landscape fragmentation from urban and transport infrastructure	LSI 004, CSI 054	EEA	km2	af	2012	1km	EU28+, TR, W. Balkan
	1	1	Fragmentation patterns of natural/seminatural landscapes	SEBI 013	CLC (ETM?)	index	fn	2006-2012	100m	EEA39
	1	1	*Effective mesh size of MAES habitats*		EEA	km2	af	?	1km	?

HI	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	1	1	Fragmentation patterns of forest landscapes	SEBI 013	CLC (ETM?)	index	f	2006-2012	100m	EEA39
	1	1	Forest connectivity	SEBI 013	CLC (ETM?)	index	f	2006-2012	100m	EEA39
	3	1	Wetland connectivity		ETC/SIA	index	n	2014	Link	EU27+, TR
	1	1	Connectivity of seminatural elements (hedgerows...)		JRC	index	a	2006	1km	EU27
			Management / disturbance intensity (pressures)							
			All ecosystems and land uses							
O	1	1	**Hemeroby**		CLC, CAPRI, AFOLU			2006	100m	EU27
O	1	2	Human Appropriation of Net Primary Production (HANPP)		UNI Klagenfurt	kg/m2 /y of C	a	1990, 2000, 2006	1km	25 MS
			Farming intensity							
OP	1	1	Intensification / extensification	AEI12	Euro-stat	index (EUR)	an	1996, 2006	NUTS2	EU 27
OP	2	1	Mineral fertilizer consumption	~SEBI 019, AEI5	CAPRI	kg/ha/y	a	2000-2015	NUTS2	EU28
P	2	1	Pesticide use	AEI06	Euro-stat	kg/ha/y of act. ingred	a	2011-2014	**MS**	EU28
	2	1	Water abstraction	AEI20	JRC?	10^6 m3/y	a	2006	5km	some MS
OP	1	1	Share of organic farming	SEBI 020, AEI4	FSS	%	a	2005, 2012-2016	**MS**	EU28
O(H)	1	1	Share of fallow land		FSS, CAPRI	%	a	2010; 2012	5km; HSU	EU28
O(I)	2	1	Crop diversity		FSS, CAPRI	1/area	a	2010; 2012	10km	EU28,HR: NUTS2
O	2	1	Crop rotation (functional crop groups)		FSS, CAPRI	1/area	a	2010	10km	EU28,HR: NUTS2
			Grazing intensity							
O	1	1	Livestock density		FSS, CAPRI	LU/ha	a	2010, 2012	5km, HSU(?)	EU28
			Forest use intensity							
O	1	2	Long term ratio of annual fellings to net annual increment	SEBI 017	EEA	%	f	1990-2010	**MS**	EEA39
O	1	2	**Length of the felling cycle**		EEA, MS	y		?	?	?
O(I)	2	3	Damage by wildlife and herbivores			m3/y timber loss	f			
O	1	3	**Game density (or ratio to sustainable levels)**		MS for-estries	%		?	?	?
			Nutrient / material balances							
OP	1	1	Gross nitrogen balance	~SEBI 019, AEI15	CAPRI	kg/ha/y	a	1990-	1km (HSU)	EU28
P	1	1	Nitrogen deposition		IMAP, LRTAP	kg/ha/y	af	2005	5km	EU
P	1	1	*Critical load exceedance for nitrogen*	SEBI 009	EEA	% of nat. area	n	2000, 2010	50km	EU27+
OP	1	1	Gross phosphorus balance	AEI16	CAPRI	kg/ha/y of P	a	1990-2016	**MS**	EU

HI	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
P	1	2	Acidification	IND-30, CSI 005, AIR 004	JRC	kg/ha/y of S	f	?	?	?
P	1	1	*Chemical status of surface/ground water*	SEBI 016	WISE	index	a	1992-	RBMP	EU
	1	1	Nitrogen concentration in surface and groundwater		DG ENV (MS reports) ?	mg/l	a			EU28?
P	1	2	Tropospheric ozone concentration	IND-30, CSI 005, AIR 004	EEA	ppb	f	1996-	**Points**	EU+
P	2	2	Heavy metal concentrations in soil		JRC D3	mg/kg/y	af	2009, 2020	1km	EU27-28
			Soil loss							
OH	2	1	Soil erosion	AEI21		t/ha/y	afn	2010	1km	EU28
OH	3	1	Loss of organic matter		LUCAS	%/y of SOC	an		1km	EU28
H	1	1	Soil sealing		CLC	ha/y	fn	2000-2012	100m	EEA39
H	1	1	Imperviousness		Copernicus	%		2006-2015	20m	EEA39
			Fire regime							
C	1	2	Number of fires		JRC-EFFIS	1/ha/y	f	1980-	Point data	EU+
C	2	2	Burnt area		JRC-EFFIS	%/y	f	1980-	250m	EU+

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Annex 2: Key definitions

Actual use or **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).

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.

Condition aspect: Meaningful groups / types of ecosystem characteristics, which should be taken into consideration for quantifying ecosystem condition in a particular assessment context. 'Condition aspects' are related to 'ecosystem condition' in the same way as 'ecosystem service types' are related to the concept of 'ecosystem services'. All condition aspects identified as relevant should be represented by quantitative condition indicators in the assessment process.

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).

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 a MAES context): An instance of 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 characteristic: Key attributes of an ecosystem unit describing its components, structure, processes, and functionality, frequently closely related to biodiversity. The term characteristics is intended to be able to encompass all of the various perspectives taken to describe an ecosystem. (based on SEEA-EEA).

Ecosystem condition: The overall quality of an ecosystem unit, in terms of its main characteristics underpinning its capacity to generate ecosystem services. The concepts of 'ecosystem state', 'ecosystem health', 'ecosystem integrity', 'ecosystem quality', and 'naturalness' are closely related to the concept of ecosystem condition.

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 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 characteristics, usually linked to specific objectives and spatial scales.

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).

MAES framework: The conceptual framework for the EU Mapping and Assessment of Ecosystem Services (MAES) programme (Target 2 Action 5 of the EU Biodiversity Strategy to 2020). The main elements of the MAES framework are the extent and condition of ecosystem types, and the capacities and flows of ecosystem service types, which need to be valuated with appropriate methods.

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: 1 (in a general context): Human induced processes that alter the condition of ecosystems. 2. (in the context of this study): recurrent patterns (regimes) of human land use activities or natural disturbances that can characterize an ecosystem in a particular place.

This glossary of terms is principally based upon **Czúcz & Condé (2017)** and **Maes et al. (2018)**. The definitions for *actual use*, *ecosystem condition* and *pressure* have been adjusted, and the terms *condition aspect* and *MAES framework* are new.

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Annex 3: List of abbreviations

AEI	agri-environmental indicator
AFOLU	agriculture, forestry and other land use
Art12	Article 12 (assessments of species under the EU Birds Directive)
Art17	Article 17 (assessments of habitats and species under the EU Habitats Directive)
BD	Birds Directive (2009/147/EC)
BGR	biogeographic region
BISE	Biodiversity Information System for Europe
CAP	common agricultural policy
CAPRI	common agricultural policy regionalised impact
CBD	Convention of Biological Diversity
CI	composite index
CICES	common international classification of ecosystem services
CLC	Corine land cover
Copernicus	the Earth observation programme of the European Commission
Corine	coordination of information on the environment
CSI	core set of indicators
DB	database
DEM	digital elevation model
DNA	deoxyribonucleic acid
EASIN	European Alien Species Information Network
EBCC	European Bird Census Council
EC	European Commission
EC~ES	ecosystem condition – ecosystem service (functional relationships)
EEA	European Environment Agency
EEC	European Economic Community
EFFIS	European Forest Fire Information System
ES	ecosystem service(s)
ESTIMAP	European Ecosystem Services Mapping tool
ET	ecosystem type(s)
ETC/BD	European Topic Centre on Biological Diversity
ETC/SIA	European Topic Centre for Spatial information and Analysis
ETC/ULS	European Topic Centre on Urban, Land and Soil Systems
ETM	European map of ecosystem types
EU	European Union
EUNIS	European Union Nature Information System
Eurostat	the statistical office of the European Union
FA	availability of floral resources
FAO	Food and Agriculture Organisation of the United Nations
FSS	farm structure surveys
GI	green infrastructure
GIS	geographic information system

HANPP	human appropriation of net primary production
HD	Habitats Directive (92/43/EEC)
HIPOC	habitat change, invasive species, pollution, overexploitation, climate change (a common list of the main drivers of environmental change)
HNV	high nature value farmlands
HRL	high resolution data layer (of Copernicus)
HSU	homogeneous spatial units (of farmlands)
IAS	invasive alien species
IBA	important bird areas
IMAP	Integrated Monitoring and Assessment Programme
INCA	integrated system for natural capital and ecosystem services accounting
InVEST	integrated valuation of ecosystem services and tradeoffs
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
KIP	knowledge innovation project
LAI	leaf area index
LoCo	local component (of Copernicus)
LRTAP	Long Range Transfer of Air Pollution
LSI	land and soil indicators
LU	livestock units
LU/LC	land use / land cover
LUCAS	Land Use/Cover Area frame statistical Survey
MA	Millennium Ecosystem Assessment
MAES	mapping and assessment of ecosystems and their services
MODIS	moderate resolution imaging spectroradiometer
MS	EU Member States
MSFD	Marine Strategy Framework Directive
MTA ÖK	Centre for Ecological Research, Hungarian Academy of Sciences
N2000	Natura 2000 (network of nature protection areas in the European Union)
NCP	Nature´s Contribution to People
NDVI	normalized difference vegetation index
NDWI	Normalized Difference Water Index
NPP	net primary production
NS	availability of nesting sites
NUTS	nomenclature of territorial units for statistics
OpenNESS	Operationalisation of natural capital and ecosystem services (EU FP7 project)
potNatVeg	potential natural vegetation
RBMP	river basin management plan
RL	red list
SDG	Sustainable Development Goals
SEBI	Streamlined European Biodiversity Indicators
SEEA-EEA	System of Environmental Economic Accounts - Experimental Ecosystem Accounts
SOC	soil organic carbon
SVL	sparsely vegetated land

TCD	tree cover density
TEEB	The Economics of Ecosystems and Biodiversity
UAA	units of agricultural area
UBA	Umweltbundesamt, Austria
UK NEA	UK National Ecosystem Assessment
WFD	Water Framework Directive (2000/60/EC)
WISE	Water Information System for Europe
WWF	World Wildlife Fund
WWPI	water and wetness probability index