European Environment Agency
European Topic Centre on
Biological Diversity

Technical paper N° 12i/2018

Ecosystem type fact sheet on wetlands

Bálint Czúcz

with contributions from Sophie Condé

December 2018

The European Topic Centre on Biological Diversity (ETC/BD) is a consortium of twelve organisations under a Framework Partnership Agreement with the European Environment Agency for the period 2014-2018
AOPK-CR Ecologic ILE-SAS ISPRA JNCC MNHN NATURALIS SC-NAT SLU S4E UBA WER

Authors' affiliation:

Bálint Czúcz, Muséum national d'Histoire naturelle (FR)
With contributions from Sophie Condé, Muséum national d'Histoire naturelle (FR)

EEA project manager:

Markus Erhard, European Environment Agency (DK)

ETC/BD production support:

Muriel Vincent, Muséum national d'Histoire naturelle (FR)

Context:

The Topic Centre has prepared this Technical paper in collaboration with the European Environment Agency (EEA) under its 2018 work programmes as a contribution to the EEA's work on ecosystem services.

Citation:

Please cite this report as
Czúcz, B. and Condé, S., 2018. Ecosystem type fact sheet on wetlands. ETC/BD report to the EEA.

Disclaimer:

This European Topic Centre on Biological Diversity (ETC/BD) Technical Paper has not been subject to a European Environment Agency (EEA) member country review. The content of this publication does not necessarily reflect the official opinions of the EEA. Neither the ETC/BD nor any person or company acting on behalf of the ETC/BD is responsible for the use that may be made of the information contained in this report.

©ETC/BD 2018
ETC/BD Technical paper N° 12i/2018
European Topic Centre on Biological Diversity
c/o Muséum national d'Histoire naturelle
57 rue Cuvier
75231 Paris cedex, France
Phone: + 33 1 40 79 38 70
E-mail: etc.biodiversity@mnhn.fr
Website: http://bd.eionet.europa.eu

Contents

1. Introduction 4
2. Key messages 5
3. Wetlands as an ecosystem type 7
4. Relevant characteristics of wetlands 8
5. Ecosystem condition indicators for wetlands 10
6. Integrating pressures among wetland condition indicators 13

Annex 1: The papers studied in the systematic review 18

Annex 2: Annotated list of potential MAES ecosystem condition indicators 22

Annex 3: Key definitions 26

Annex 4: List of abbreviations 29

1. Introduction

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 to 2020 calls Member States (MS) to maintain and restore the ecosystems and their services. To meet these goals an EU wide ecosystem assessment (the EU MAES assessment: "Mapping and Assessment of Ecosystems and their Services" – Maes et al., 2013; 2014; 2018; Erhard et al., 2016) will evaluate the condition of Europe's ecosystems and the services they provide to the society based on an analysis of available data. The assessment will cover the whole EU territory, including EU regional seas, and it complements the Member States' activities on mapping and assessment of ecosystems and their services. The EU MAES assessment serves two main policy requests: (1) provide an evaluation of Target 2 of the EU Biodiversity Strategy to 2020 and (2) provide support to the definition of smarter targets under the post-2020 biodiversity policy.

Ecosystem condition has a key role in the EU MAES assessment: adequate service provision requires healthy ecosystems in good condition (Fig. 1.1; Maes et al., 2014). The EU MAES assessment will evaluate the condition of ecosystems based on a set of key indicators in the context of 'thematic ecosystem assessments', grouped according to broad ecosystem types (urban ecosystems, agroecosystems (croplands and grasslands), forests, heathlands, wetlands, freshwater, and marine ecosystems; Maes et al., 2018). The assessment aims to evaluate the trends in the condition of Europe's ecosystems relative to a baseline situation (2010) and provide evidence on where ecosystems are in a degraded state. This series of fact sheets produced by ETC/BD gives additional guidance on how ecosystem condition can be meaningfully defined and measured for various services and in various ecosystems, based on a review of scientific studies (Czúcz et al., 2017, 2018).

In the following pages key messages are summarized first from a policy perspective: what can these studies teach about designing a relevant set of ecosystem condition indicators for the EU MAES assessment? Then, in the subsequent chapters these lessons will be expanded, giving a detailed account of how wetlands are defined, which wetland characteristics are relevant for various ES, and what kind of indicators are available for these characteristics. The fact sheet is then concluded by a set of annexes, which contain all relevant metadata behind the whole analysis.

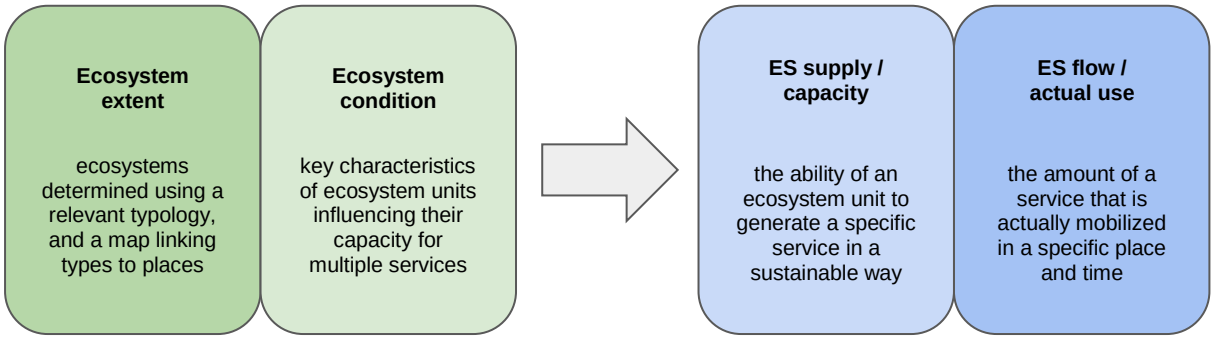

Figure 1.1: A simplified representation of the MAES conceptual framework (based on Maes et al., 2014; Burkhard et al., 2018; and MAES-INCA, 2018). The four boxes describe the main elements which need to be quantified (mapped and assessed) during the EU MAES assessment process.

2. Key messages

Wetlands are predominantly waterlogged habitats with the water table at or above ground level for at least half of the year. Even though wetlands constitute a just relatively small fraction of Europe's natural ecosystems, their contribution to ecosystem services and thus human well-being is disproportionately larger. There are several characteristics of wetlands that influence which services they will be able to provide, and to what degree.

- The most important characteristic of wetlands is that they are wet (almost) all the time. If there is not enough water, wetlands will fail to deliver, and this can affect all services, supplied by wetlands (Fig. 2.1). The **water availability** of wetlands can be characterised by space-borne observations detecting water stress in vegetation (*normalized difference water index, NDWI*). It would be important to develop land-based indicators as well.
- The **amount of vegetation (biomass)** is also a simple but relevant wetland characteristic that affects multiple regulating ecosystem services. There are several characteristics and indicators that can be relevant here, but preferably only a single (or very few) carefully selected indicator (e.g. *annual mean NDVI*) should be included in EU MAES, as most of the potential indicators are correlated / redundant.
- **Biodiversity** is also a key factor in the case of wetlands. In Europe wetlands are clear biodiversity hotspots, providing habitat for a high number of birds, amphibians, reptiles and many other iconic species, insects and mammals. Due to their importance and the long tradition in monitoring them, *wetland birds* seem to be the best choice as the basis for a relatively general wetland biodiversity indicator. Several components of the *ecological status* indicators monitored for the *EU Water Framework Directive* (WFD) can also be relevant for wetlands.

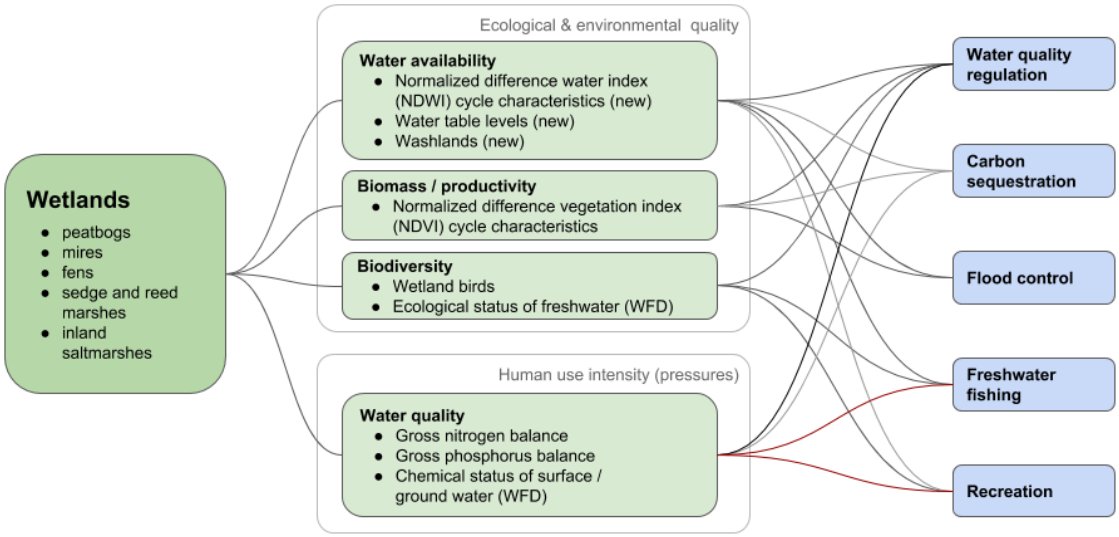

Figure 2.1: A graphical summary of this fact sheet listing *relevant aspects of wetland condition*, together with their *key indicators*, and connecting them to the *ecosystem services* they influence. Condition–service connections are drawn based on a systematic review (Czúcz et al., 2018). The negative relationships and the most important data gaps are highlighted in red.

Wetlands, as typically 'downstream' ecosystems are highly exposed to the human pressures, particularly to pollution derived from land use and economic activities. Several indicators related to **pollution** are highly relevant for wetland ecosystems:

- *Gross nutrient balances* (nitrogen, phosphorus) of the encompassing landscape can be directly relevant pressure indicators for wetlands.
- The chemical quality of the surface and groundwater in a wetland are also of key importance. Several components of the *WFD chemical status* indicators can be relevant for wetlands.

3. Wetlands as an ecosystem type

Inland wetlands are predominantly waterlogged habitats with the water table at or above ground level for at least half of the year, dominated by herbaceous or ericoid vegetation (Maes et al., 2013; EEA, 2012). This ecosystem type includes natural or modified mires, bogs and fens (Maes et al., 2013), inland saltmarshes, and waterlogged habitats where the groundwater is frozen (EEA, 2012). Nevertheless, waterlogged herbaceous vegetation connected to open water is considered to be part of the neighbouring *rivers and lakes*, waterlogged habitats dominated by trees or large shrubs are considered as *heathlands* or *forests* (F9, G1, G3 in EUNIS), and rice fields belong to *croplands*.

According to EUNIS there are 6 major subtypes of wetlands (Table 3.1), many of which are confined to specific biogeographic regions. In order to make the wetland subtypes available for the EU MAES assessment, the European map of ecosystem types (ETM) addresses this level of thematic resolution based on a CLC crosswalk refined with the most recent available spatial datasets (Weiss & Banko, 2018; Table 3.1). According to ETM v3.1, just 2% of all European ecosystems are wetlands, and the overwhelming majority of these wetlands belong to just 2 subtypes (D1, D3) specific to Atlantic, Nordic and mountain areas. The share of each wetland subtype is also shown in Table 3.1.

Table 3.1: The most important subtypes (EUNIS level 2) of wetlands available in the European map of ecosystem types (ETM v3.1), linked to CLC classes and other datasets used during the map generation (based on Weiss & Banko, 2018). The share of each subtype is given in parentheses after the subtype names.

EUNIS level 2 subtypes (+their share)		Original CLC class	Assignment rules
D1	Raised and blanket bogs (40.7%)	412 Peatbogs	if within D1 distribution in Art.17 DB (~in Art.17:D1; priority 2)
		412 Peatbogs	if no other rule applies
D2	Valley mires, poor fens and transition mires (2.1%)	411 Inland marshes*	if in Art.17:D2 AND NOT in Art.17:D4 (priority 3)
		411 Inland marshes*	if in Art.17:D2 (priority 6)
D3	Aapa, palsa and polygon mires (45.4%)	412 Peatbogs	if in Art.17:D3 (priority 1)
		412 Peatbogs	in alpine, boreal and atlantic zone (potnatVeg) (priority 3)
D4	Base-rich fens and calcareous spring mires (0.5%)	411 Inland marshes*	if in Art.17:D4 AND NOT in Art.17:D2 (priority 4)
		411 Inland marshes*	if in Art.17:D2 AND in Art17:D4 AND soil is calcareous (priority 5)
D5	Sedge and reedbeds, normally without free-standing water (7.2%)	411 Inland marshes*	if in Art.17:D5 (priority 2)
		411 Inland marshes*	if no other rule applies
D6	Inland saline and brackish marshes and reedbeds (4.1%)	411 Inland marshes*	if in Art.17:D6 (priority 1)

* grid cells of CLC 411 (inland marshes) adjacent to lakes (CLC 512) were marked as C3 (littoral zone of inland surface waterbodies)

As it can be seen, whenever there is even a little permanent and open water surface adjacent to a reedbed the whole habitat is considered a lake (more specifically as C3, the littoral zone of a lake). This delineation is highly arbitrary, and can even create some 'singularities' in detecting ecosystem change (at each renewal of the ETM large areas can be moved from one ET to another at each remapping just because of relatively small changes in a few pixels). Similarly, in terms of functionality and services the littoral zones of lake (0.04% of the whole ETM, which amounts to ~28% of the area of D5, the 'freestanding' reedbeds) can also be considered as a 'wetland' ecosystem type. As a large portion of the literature did not distinguish littoral wetlands from 'real' wetlands either, this type was included into the following discussions as well.

4. Relevant characteristics of wetlands

Table 4.1 provides an overview on the importance of various characteristics in enabling wetlands to supply services. According to the scientific literature sampled in the underlying systematic review (Czúcz et al., 2018), the most relevant wetland characteristics are the availability and quality of water, the amount of biomass, and their biodiversity (plants/macrophytes in particular). These attributes of the wetlands influence several ES, including *water quality regulation*, *flood control*, *freshwater fishing*, and *recreation*.

Table 4.1: Results of the systematic review: wetland characteristics that have been documented to influence the supply of various services (based on Czúcz et al., 2018). Total / positive / negative / mixed: the number of papers which document any (or positive / negative / mixed) relationships between the studied characteristics and any ecosystem service.

Characteristics type	Total	Positive	Negative	Mixed	Ecosystem services*
Water availability / quality	**6**	4	0	0	flood, fish, w.qual
washland (regularly flooded land)	**4**	4	0	0	flood, fish
water levels	**2**	1	1	0	flood, w.qual
The extent (abundance) of wetlands (or a subtype)	**5**	5	0	0	w.qual
Biodiversity (in general)	**3**	2	0	1	w.qual, recr
diversity of plants	**1**	1	0	0	w.qual
Biomass at the site	**3**	1	0	2	w.qual, flood
total [height]	**2**	1	0	1	flood, w.qual
ground layer	**1**	0	0	1	w.qual
litter	**1**	0	0	1	w.qual
Site structure	**2**	1	1	0	flood, w.qual
Occurrence / abundance of a specific species (functional) group	**1**	1	0	0	w.qual
macrophytes	**1**	1	0	0	w.qual
Landscape diversity	**1**	1	0	0	fish

* Ecosystem services: fish: freshwater fishing; flood: flood protection; w.qual: water quality regulation; recr: recreation

First of all it is important to emphasize that even though wetlands constitute a **relatively small part** (2%) of European landscapes, their contribution to the ecosystem services and thus human well-being is disproportionately larger. This is particularly true for the non D2/D3 wetlands, which only occupy **0.31%** of Europe's terrestrial territories. This means that the **mere presence of wetlands** can be considered as a good 'landscape quality indicator', or even an ES proxy for specific services (e.g. *water quality regulation*, Vought et al., 1995; Hefting et al., 2013; or *microclimate regulation*, Sun et al., 2012). On the other hand, in order to be consistent with the conceptual framework (Fig. 1.1) the (total) area / amount of wetlands is already taken into account as 'ecosystem extent', so it should not be considered as an ecosystem condition aspect too. Creating a wetland condition indicator based on just the (changes in) extent of wetlands would introduce a serious inconsistency into the EU MAES assessment, no matter how important the amount of wetlands is from an ES, conservation or policy perspective.

As it could be seen in the previous chapter, the presence of water is the key defining characteristic of wetlands, so it should not be any surprise that it is also of key importance from a functional perspective. The **quantity / availability of water** on wetlands has many aspects (timing, fluctuations), and it is not easy to capture the essence of temporally and spatially highly variable water availability patterns in a few key variables. For an adequate functioning and thus for many services (*water quality regulation*: McCartney et al., 2003; *carbon sequestration*: Peichl et al., 2014; Olefeldt et al., 2017) a **relatively high water table with stable levels** and minimal dry periods can be considered as a good state. Wetland soils may contain significant carbon pools which might be immobilized during prolonged dry periods, and the organisms that sustain *water quality regulation* might also get lost in such dry spells. For *flood control* the ideal **water level regime** is different:

wetlands should be relatively "empty" most of the time (when the floods can be expected), and then they should endure a few weeks of very high water levels. Several studies (Morris et al., 2005; Acreman et al., 2011) distinguished freely flooded wetlands (or grasslands, croplands) as **washlands**, underlining the important role of these ecosystem subtypes in providing *flood regulation*. Occasionally inundated habitats can also play an important role in creating capacities for *freshwater fishing* as they can be ideal habitats for fish reproduction (Lapointe et al., 2014).

Water quality is also an obvious choice for a wetland state descriptor, which is intimately connected to the ES of *water quality regulation* (McCartney et al., 2003; Fisher et al., 2009). Water quality of wetlands (especially littoral ones) can also influence capacities for *recreation* (Roebeling et al., 2016). Changes in water quality (e.g. in the case of artificial wetlands: Scholz et al., 2007; Weisner et al., 2010) should, however be seen *as an ES indicator*, rather than an aspect of condition.

The **mass of plant matter (biomass)** at wetland sites can also be relevant for both *water quality regulation* and *flood control*, but the direction of the relationship is slightly different in the two cases. In the case of *flood control* (especially the 'downstream service', see the dedicated fact sheet: Czúcz & Sonderegger, 2018) too much biomass causes hydraulic roughness, and can thus weaken the service (Morris et al., 2005), whereas for *water quality regulation*, the more biomass seems to be always the better (McCartney et al., 2003; Weisner et al., 2010).

The **biodiversity** of wetlands is important from two perspectives. The diversity of (1) several organisms (plants, insects, birds) can be seen as an **'overall' state indicator** of the quality of the wetland as a habitat. From this aspect wetland biodiversity can be considered as the biotic (ecological status) components of the WFD indicators, as it integrates several aspects of water quantity and quality, and many other potential pressures (Van den Broeck et al., 2015). On the other hand (2) **functional diversity**, and in particular the presence / abundance of a few key functional groups (e.g. macrophytes, insects, microorganisms) are needed to maintain the processes underlying water quality regulation processes (Fisher et al., 2009). Wetlands may also serve as means for seed dispersal for specialised organisms (Brock et al., 2003). Wetlands can also contribute to the **landscape diversity** underlying capacities for *recreation* (van Berkel & Verburg, 2014).

The **EUNIS subtypes** distinguished in ETM 3.1 (see Table 3.1) are also relevant proxies for the some ecosystem services. The carbon pools under peatbogs (D1, D3) are typically much larger than in the case of other subtypes (e.g. D5, D6, C3), and this could be an important factor for *atmospheric carbon regulation* ('avoided emission', see the dedicated fact sheet: Schwaiger & Czúcz, 2018) capacities. Some rare EUNIS types (e.g. D4) can also be seen as a proxy for rich biodiversity and high naturalness (Jiménez-Alfaro et al., 2014).

5. Ecosystem condition indicators for wetlands

The ecosystem characteristics listed in Table 4.1 are not fully independent from each other. Biodiversity, for example, is roughly determined by habitat type, landscape context, and land use intensity. Thus not all of the identified / proposed aspects need to be covered by an ideal indicator system in order to be relatively comprehensive. A well-chosen set of key indicators can largely describe all aspects of wetland condition that are relevant from the perspective of services.

A lot of efforts have been already invested into develop relevant ecological and environmental indicators, both at the global and the European level. Indicators broadly vary in terms of their spatial, temporal and thematic scope, their spatial and temporal resolution, and their reliability. With some additional efforts, further indicators may become available. In the EU MAES context, the 5th MAES report (Maes et al., 2018) compiled a good starting set of condition indicators for all of the MAES ecosystem types. Annex 2 matches this list to the outcomes of the systematic review, giving a detailed overview of all indicators that can be seen as relevant for wetlands. Table 5.1 is a shorter version of Annex 2, which gives a diagnostic overview for each potential condition indicator (with the exception of the pressure / management / disturbance intensity indicators, which will be discussed in the next chapter).

Table 5.1: Indicators available for the ecosystem characteristics relevant for wetlands. The 'usefulness' of each indicator is highlighted with a colour scheme following that of the 2nd MAES report (Maes et al., 2014) – see details in Annex 2. Proposed **key indicators** are highlighted in bold.

U	Indicator name	Comments
	Biodiversity (diversity/abundance of major species groups)	
	species in general	
2	Conservation status and trends of species of community interest (for multiple ET)	multiple indicators (one for each ET), only available at a very coarse spatial resolution
2	Red List Index of threatened species	multiple indicators (one for each ET), at a very coarse spatial resolution
2	Living Planet Index for Mediterranean wetlands	a similar index extended to whole EU would be more useful
2	Invasive alien species (richness)	the number of IAS can be negatively correlated with general biodiversity
3	Species diversity, richness (number and abundance of species, including vascular plants, vertebrates, etc)	proposed by forest pilot but can be relevant for more ETs, needs to be developed, data source unclear
	plants	
3	Plant functional types (diversity)	proposed by forest pilot but can be relevant for more ETs, needs to be developed, data source unclear
3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)	proposed by forest pilot, needs to be developed, data source unclear
	birds	
2	EU Population status and trends of bird species (%)	only available at a very coarse spatial resolution
2	**Bird indices (farmland, forest...)**	multiple indicators (one for each ET), the most accessible biodiversity indicator (probably the only one which can be refined to a spatial resolution beyond NUTS2 based on existing data)
	insects	
2	Grassland Butterfly Indicator	only available at a very coarse spatial resolution, may be also partly relevant for wetlands
	habitats	
2	Conservation status and trends of habitats of community interest	multiple indicators (one for each ET), only available at a very coarse spatial resolution
2	Threatened habitat cover	multiple indicators (one for each ET), at a very coarse spatial resolution
1	Naturalness (index or typology)	is conceptually close to "hemeroby", still needs to be implemented
2	Red List Index of threatened habitats	multiple indicators (one for each ET), still needs to be developed, will be of a low resolution, & no time series
1	**Ecological status of surface water bodies**	multiple indicators (some of the components might be more relevant for wetlands than the most aggregated indices)

Table 5.1 continued.

U	Indicator name	Comments
	Biomass at the site	
1	**Normalized difference vegetation index (NDVI)**	instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators; a single biomass indicator can be enough
1	Leaf Area Index (LAI)	see above
	Site structure	
1	Structural heterogeneity	
	Water availability	
1	**Water and wetness probability index (WWPI)**	a key wetland characteristic, which can even be used for their delineation on ETM
1	**Normalized difference water index (NDWI)**	instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators
3	Water levels	the 'degradable environmental stock' linked to the process of draining/desiccation, needs to be developed, data source unclear
2	**Washlands (regularly flooded areas)**	could also be considered as a subtype or a (generally positive) pressure, to be developed
	The extent (abundance) of a specific subtype (of the target ecosystem type)	
1	Extent of ETM subtypes	EUNIS (level 2) subtypes themselves can be considered as being of different levels of condition (or naturalness, hemeroby, etc.)
2	Density of embedded seminatural elements (hedgerows, lines of trees, etc.)	if these elements are seen as parts of the embedding wetland ecosystem type
2	HNV area	the share of this highly relevant 'subtype' might be redundant with other indicators (seminatural elements, pressures, etc.)
	The coexistence / proximity of two different ecosystem types	
2	Proximity to water	wetlands connected to water bodies are considered to be part of the freshwater ET!
	Landscape diversity	
1	Landscape diversity	can be relatively easily developed
	Landscape fragmentation & connectivity	
2	Landscape fragmentation from urban and transport infrastructure	a new EEA indicator based on the joint fragmentation (effective mesh size) of all natural & managed ecosystems
1	Fragmentation patterns of natural/seminatural landscapes	could be (re)calculated using effective mesh sizes for coherence (fragm.geom: nat. ecosystems vs. everything else)

** U: 'usefulness' score, which follows the 'traffic lights' scheme of the 2nd MAES report (Maes et al., 2014):*

1 *highly relevant for the specified aspect of forest condition, appropriate data are available at European scale, and easily understood by non-technical audiences (relevance, representativity, and data availability are all high – see details in in Annex 2)*

2 *relevant for the specified aspect of forest condition, some data are available, but still needs some work, or the indicator is difficult to be interpreted for non-technical audiences (relevance, representativity, or data availability is moderate)*

3 *relevant for the specified aspect of forest condition, but there are significant data or interpretation challenges (e.g. the indicator is just weakly linked to the characteristics that it is intended to indicate, thus representativity or data availability is low)*

As it could be seen the most important 'defining' characteristics of wetlands is the amount / availability of water. If there is not enough water, the wetland even stops to be a wetland (ecosystem change). There are many options to characterize water availability with indicators. The **water and wetness probability index (WWPI)** characterizes the frequency of surface water cover based on remote sensing data, which could even be used for the delineation of wetlands on ETM. The **normalized difference water index (NDWI)** characterizes the water stress experienced by vegetation also based on remote sensing observations. **Soil moisture** content can also be modelled based on meteorological observations, but unfortunately in the case of many wetland types (which don't rely directly on precipitation as their primary water source) this approach might be considerably less reliable. In both cases (remote sensing, modelling) the instantaneous water availability values are of little information, but multiannual statistics (averages or extremities) can be of much more relevance as condition indicators. The simplest and most easily communicable indicator for wetland condition would perhaps be the (changes in) **water table levels**, if such data were available.

The quality of the water in wetlands is also an important aspect of water condition. Water quality can best be characterised by **ecological status** and **chemical status** indicators from the EU Water

Framework Directive (WFD). For wetlands, the **chemical status of groundwaters** can be of particular important, but other WFD indicators should also be reviewed for potential applicability as wetland condition indicators. (Chemical status is directly related to pressures so it is listed in Table 6.1.)

There are also several options available to reliably characterize the amount of green biomass in wetlands based on remote sensing. The most reliable and readily available option is probably the **normalized difference vegetation index (NDVI)**, but the easily communicable **leaf area index (LAI)** might offer a second choice. However, it is important to emphasize again that a well-chosen multiannual statistics (e.g. mean annual maxima) can be much more relevant than the instantaneous values.

As for the biodiversity of wetlands, there are much fewer reliable data sources. Most of the existing indicators seem to be problematic in terms of spatial and temporal resolution. The only taxonomic group for which there is a chance that an EU-level index with adequate (= at least NUTS2) resolution can be generated in the foreseeable future is birds. Given the high importance of wetlands as bird habitats, a **wetland birds index** seems to be a good choice as an key biodiversity indicator for this ET. As a second choice some of the **WFD ecological status** indicators can also be relevant for wetlands. On the part of the research community there have been considerable efforts to develop simple but efficient WFD-compatible ecological status indicators specifically for wetlands (e.g. Quintana et al., 2015; van den Broeck et al., 2015).

6. Integrating pressures among wetland condition indicators

The intensity (frequency or magnitude) of recurrent human management activities and/or (semi)natural disturbance regimes can also be conceptualised and considered as ecosystem characteristics. These 'management/disturbance characteristics' highly influence the capacity of the ecosystems to supply various services. In the MAES conceptual framework (Maes et al., 2013; 2014; 2018) these characteristics are listed under the heading "pressures", which are considered an "indirect approach" for measuring ecosystem condition (Erhard et al. 2016, p.31). However, most 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.) which is directly affected by the pressure. In most cases there are indicators available for both the 'pressure' (as a flux, flow or rate of change) and the underlying state variable. Wherever available, variables describing such 'degradable environmental stocks' (that are being degraded due to the specific pressures) are highly appropriate for use as condition indicators for the EU MAES assessment. This choice makes it possible to link pressures to changes in condition without compromising the conceptual integrity of the assessment.

Following the logic of the systematic review, pressure indicators have been clustered according to the ecosystem types and their typical management activities/disturbance regimes instead of the HIPOC categories. From the HIPOC classes, *overexploitation* and *pollution* can be relatively easily considered as ecosystem characteristics, and thus their indicators are well represented in Table 6.1. *Climate change* and *biological invasions* are, however, much more indirect pressures, with very few indicators that can be conceptualized as characteristics belonging to specific ecosystems. Finally, processes related to *habitat loss* should not be considered as ecosystem condition changes. The extent of each ecosystem type belongs to the 'ecosystem extent' box in Figure 1.1, and should be accounted for in other parts of the MAES assessment report. This is does not mean that wetland loss is not important: it is of key importance indeed. But, wetland loss (as any other habitat transformation) is already accounted for in the ecosystem extent assessment (mapping) part of the work, and including this topic also into the condition chapters, would be a sort of 'double counting'.

Accounting for habitat transformations has to be done particularly carefully in the case of wetlands because of the special way how wetlands and lakes are delineated on the ETM. For example if in a vast wetland for any reason a few pixels of open water surface suddenly appears, then the whole wetland will be automatically flipped into a freshwater ecosystem type (C3). On the contrary, if a small lake encircled by a vast "littoral" wetland suddenly 'closes up' (i.e. gets completely vegetated) then the whole system will turned from a lake into a wetland on the ecosystem type map. This can appear to be as a huge wetland loss or wetland gain, even if there was hardly any physical change in the system. So any ETM interpretation of wetland gains or losses should be aware of these potential artefacts.

Even though the systematic review has not identified directly any 'management / disturbance intensity' characteristics (Table 4.1), there are still several 'pressure-related' indicators that are relevant for wetlands (Table 6.1). Indicators related to water quality are of key importance among them. **Gross nitrogen and phosphorus balance** can be seen as critically important pressures for wetlands, as well as the WFD **chemical status** variables, that have been already mentioned in the previous chapter.

Table 6.1: **Indicators available for pressures relevant for wetlands**. The 'usefulness' of each indicator is highlighted with a colour scheme following that of the 2nd MAES report (Maes et al., 2014) – see details in Annex 2. Proposed **key indicators** are highlighted in bold.

	Indicator name	Comments
	All ecosystems and land uses	
1	Hemeroby	a newly proposed condition indicator with a long history, conceptually close to "naturalness", still needs to be implemented
	Farming intensity	
2	Intensification / extensification	only available at NUTS2 level
2	Mineral fertilizer consumption	only available at NUTS2 level
2	Pesticide use	describes pesticide sales not pesticides use, different pesticides are simply added, at a very coarse spatial resolution
2	Water abstraction	water levels are a more direct state variable than water abstraction
2	Share of organic farming	only available at a very coarse spatial resolution
	Grazing intensity	
2	Livestock density	
	Nutrient / material balances	
1	**Gross nitrogen balance**	
1	Nitrogen deposition	
1	Critical load exceedance for nitrogen	multiple indicators (one for each ET)
1	**Gross phosphorus balance**	only available at a very coarse spatial resolution
2	Acidification	
1	**Chemical status of surface/ground water**	multiple indicators (some of the components might be more relevant for wetlands than the most aggregated indices)

** U: 'usefulness' score, which follows the 'traffic lights' scheme of the 2nd MAES report (Maes et al., 2014):*

1 *highly relevant for the specified aspect of forest condition, appropriate data are available at European scale, and easily understood by non-technical audiences (relevance, representativity, and data availability are all high – see details in in Annex 2)*

2 *relevant for the specified aspect of forest condition, some data are available, but still needs some work, or the indicator is difficult to be interpreted for non-technical audiences (relevance, representativity, or data availability is moderate)*

3 *relevant for the specified aspect of forest condition, but there are significant data or interpretation challenges (e.g. the indicator is just weakly linked to the characteristics that it is intended to indicate, thus representativity or data availability is low)*

As the main sources for water pollution several aspects of agricultural management intensity can also be seen as relevant for wetlands, including **agricultural intensification**, **fertilizer** and **pesticide use**, and the share of **organic farming**. Similarly, high **grazing intensity** levels in grasslands can also lead to an increased pollution in neighbouring / downstream wetlands. And agricultural **water abstraction** can be related to dropping water tables, and can thus be also relevant in wetlands.

References

Acreman M. C., R. J. Harding, C. Lloyd, N. P. McNamara, J. O. Mountford, D. J.; Mould, B. V. Purse, M. S. Heard, C. J. Stratford & S. J. Dury (2011). Trade-off in ecosystem services of the Somerset Levels and moors wetlands. Hydrological Sciences Journal, 56, 8, 1543.

Brock, M. A., Nielsen, D. L., Shiel, R. J., Green, J. D., & Langley, J. D. (2003). Drought and aquatic community resilience: the role of eggs and seeds in sediments of temporary wetlands. Freshwater Biology, 48(7), 1207-1218.

Burkhard, B., Santos-Martin, F., Nedkov, S., & Maes, J. (2018). An operational framework for integrated Mapping and Assessment of Ecosystems and their Services (MAES). One Ecosystem, 3, e22831. https://doi.org/10.3897/oneeco.3.e22831

Czúcz, B., Götzl, M., Schwaiger, E., Schwarzl, B., & Sonderegger, G. (2017). Working paper on functional relationships between ecosystem characteristics and services in support of condition assessment. ETC/BD report to the EEA. https://bd.eionet.europa.eu/Reports/ETCBD TechnicalWorkingpapers/PDF/Functional_relationships_ecosystem_condition_assessments.pdf

Czúcz, B. & Sonderegger, G. (2018). Ecosystem service fact sheet on flood regulation. ETC/BD Working Paper. (Task 175A)

EEA (2012) EUNIS habitat classification 2007 (Revised descriptions 2012). https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification/

Erhard M, Teller A, Maes J, Meiner A, Berry P, Smith A, ..., Christiansen T (2016): Mapping and Assessment of Ecosystems and their Services. Mapping and Assessing the condition of Europe's ecosystems: Progress and challenges. 3rd Report. Publications office of the European Union, Luxembourg. http://catalogue.biodiversity.europa.eu/uploads/document/file/1328/ 3rdMAESReport_Condition.pdf

Fisher, J. Stratford, C.J., Buckton, S. (2009) Variation in nutrient removal in three wetland blocks in relation to vegetation composition, inflow nutrient concentration and hydraulic loading. Ecological Engineering 35, 1387-1394

Hefting, Mariet M., Ronald N. van den Heuvel and Jos T.A. Verhoeven (2013) Wetlands in agricultural landscapes for nitrogen attenuation and biodiversity enhancement: Opportunities and limitations . Ecological Engineering 56: 5– 13

Jiménez-Alfaro, B., Hájek, M., Ejrnaes, R., Rodwell, J., Pawlikowski, P., Weeda, E. J., … Díaz, T. E. (2014). Biogeographic patterns of base-rich fen vegetation across Europe. Applied Vegetation Science, 17(2), 367–380.

Lapointe, N. W. R., S. J. Cooke, J. G. Imhof, D. Boisclair, J. M. Casselman, R. A. Curry, ... W. M. Tonn (2014). Principles for ensuring healthy and productive freshwater ecosystems that support sustainable fisheries. Environmental Reviews 22: 110-134

Maes J, Teller A, Erhard M, Liquete C, Braat L, Berry P, … Bidoglio G (2013). Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. Publications office of the European Union, Luxembourg. http://ec.europa.eu/environment/nature/knowledge/ ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

Maes J, Teller A, Erhard M, Murphy P, Paracchini ML, Barredo JI, … Lavalle C (2014). Mapping and Assessment of Ecosystems and their Services: Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. 2nd Report. Publications office of the European Union, Luxembourg. http://catalogue.biodiversity.europa.eu/uploads/document/ file/1230/ 2ndMAESWorkingPaper.pdf

Maes J, Teller A, Erhard M, Grizzetti B, Barredo JI, Paracchini ML, … Werner B (2018). Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition. Publications office of the European Union, Luxembourg. https://biodiversity.europa.eu/maes

MAES-INCA (in prep.): Natural Capital Accounting: Overview and Progress in the European Union. Publications office of the European Union, Luxembourg. https://biodiversity.europa.eu/maes (the 6th MAES report, still in progress...)

McCartney, M. P., C. Stratford, Neal, C., et al. (2003) Seasonality and water quality trends in a maturing recreated reed bed. Science of the Total Environment 314: 233-254.

Morris, J, Hess, T.M., Gowing, D.J.G., Leeds-Harrison, P.B., Bannister, M., Vivash, R.M.N. and Wade. M. (2005) A framework for integrating flood defence and biodiversity in washlands in England. International Journal of River Basin Management, 3, 2, 105-115.

Olefeldt, D., Euskirchen, E. S., Harden, J., Kane, E., McGuire, A. D., Waldrop, M. P., & Turetsky, M. R. (2017). A decade of boreal rich fen greenhouse gas fluxes in response to natural and experimental water table variability. Global Change Biology, 23(6), 2428–2440.

Peichl, M., Öquist, M., Löfvenius, M. O., Ilstedt, U., Sagerfors, J., Achim Grelle, … Nilsson, M. B. (2014). A 12-year record reveals pre-growing season temperature and water table level threshold effects on the net carbon dioxide exchange in a boreal fen. Environmental Research Letters, 9(5), 055006.

Quintana, X. D., Cañedo-Argüelles, M., Nebra, A., Gascón, S., Rieradevall, M., Caiola, N., … Boix, D. (2015). New Tools to Analyse the Ecological Status of Mediterranean Wetlands and Shallow Lakes. In Experiences from Surface Water Quality Monitoring (pp. 171–199). Springer, Cham.

Roebeling, P., Abrantes, N., Ribeiro, S., & Almeida, P. (2016). Estimating cultural benefits from surface water status improvements in freshwater wetland ecosystems. Science of The Total Environment, 545–546, 219–226.

Schwaiger, E., & Czúcz, B. (2018). Ecosystem service fact sheet on carbon sequestration. ETC/BD Working Paper. 175A

Scholz, M., A. J. Sadowski, Harrington, R., et al. (2007) Integrated Constructed Wetlands assessment and design for phosphate removal. Biosystems Engineering 97(3): 415-423.

Sun, R., Chen, A., Chen, L., & Lü, Y. (2012). Cooling effects of wetlands in an urban region: The case of Beijing. Ecological Indicators, 20, 57–64.

van Berkel, Derek & Peter H. Verburg (2014) Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. Ecological Indicators 37: 163– 174

van den Broeck, M., Waterkeyn, A., Rhazi, L., Grillas, P., & Brendonck, L. (2015). Assessing the ecological integrity of endorheic wetlands, with focus on Mediterranean temporary ponds. Ecological Indicators, 54, 1–11.

Vought, L. B. M., G. Pinay, Fuglsang, A., et al. (1995) Structure and function of buffer strips from a water-quality perspective in agricultural landscapes. Landscape and Urban Planning 31(1-3): 323-331.

Weisner, S. E. B. And G. Thiere (2010) Effects of vegetation state on biodiversity and nitrogen retention in created wetlands: a test of the biodiversity-ecosystem functioning hypothesis. Freshwater Biology 55(2): 387-396.

Weiss, M., Banko, G. (2018). Ecosystem Type Map 2012 v3.1 – Terrestrial ecosystems and integration of marine part. ETC/BD report

Annex 1: The papers studied in the systematic review

Table A1: This table identifies the scientific papers related to the ES pollination, that were reanalysed from the OpenNESS systematic review (Smith et al., 2017). The table follows the structure of Table 4.1, linking each 'functional relationship' documented to the underlying papers using unique IDs, which are resolved below this table. The codes in brackets (e.g. "[T mi]") link the main types of characteristics to the types listed in Czúcz et al. (2017), where all further details about the characteristics typology and the reanalysis work can be found. Columns TT and NN give an overview on the importance of each characteristic for pollination:

- **TT**: total influence (the number of papers which document an effect of the characteristics on any of the studied ES in any ecosystem type);
- **NN**: net influence (the number of papers documenting a positive ES effect minus the number of papers with a negative effect; mixed effects are not counted).

Higher values of TT are highlighted in darker shades in order to give a better visual overview of the importance of each line, and negative numbers in column NN are highlighted in red. All of the remaining columns refer to the studied ecosystem services (tim: timber production; fish: freshwater fishing; poll: pollination; pest: pest regulation; carb: carbon sequestration; ero: erosion protection; flo: flood protection; w.q: water quality regulation; rec: recreation; a.q: air quality regulation). The values in these columns are the unique IDs of the scientific papers, which document a 'functional relationship' and the specific ecosystem characteristic in the given ecosystem type. The IDs of the papers are resolved in a reference list at the end of this Annex.

Characteristics type	TT	NN	tim	fish	poll	pest	carb	ero	flo	w.q	rec	a.q
Biodiversity (in general) [T di]	3	2								169, 654	470	
diversity of plants	1	1								654		
Occurrence / abundance of a specific species (functional) group [T ab]	1	1								654		
macrophytes	1	1								654		
Biomass at the site [T bi]	3	1							267	169, 184		
total [height]	2	1							267	169		
ground layer	1	0								184		
litter	1	0								184		
Site structure [T st]	2	0							242	169		
Water availability / quality [T wa]	6	4		525, 678					242, 255, 267	184		
washland (regularly flooded land)	4	4		525					242, 255, 267			
water levels	2								255	184		
The extent (abundance) of wetlands (or a subtype) [E ab]	5	5								92, 184, 230, 375, 482		
Landscape diversity [L di]	1	1		525								

References

9 Steinbeiss, S., Beßler, H., Engels, C., Temperton, V. M., Buchmann, N., Roscher, C., Kreutziger, Y., Baade, J., Habekost, M. and Gleixner, G. (2008) Plant diversity positively affects short-term soil carbon storage in experimental grasslands. Global Change Biology, 14, 12, 2937-2949. https://doi.org/10.1111/j.1365-2486.2008.01697.x

22 Nadal-Romero, E., T. Lasanta and J. M. Garcia-Ruiz (2013) Runoff and sediment yield from land under various uses in a Mediterranean mountain area: long-term results from an experimental

station. Earth Surface Processes and Landforms 38: 346-355 https://doi.org/10.1002/esp.3281

58 Farwig, N., Bailey, D., Bochud, E., Herrmann, J. D., Kindler, E., Reusser, N., Schueepp, C. and Schmidt-Entling, M. H. (2009) Isolation from forest reduces pollination, seed predation and insect scavenging in Swiss farmland. Landscape Ecology, 24(7), 919-927. https://doi.org/10.1007/s10980-009-9376-2

121 Pohl, M., F. Graf, A. Buttler and C. Rixen (2012) The relationship between plant species richness and soil aggregate stability can depend on disturbance. Plant and Soil 355: 87-102 https://doi.org/10.1007/s11104-011-1083-5

140 Albrecht, M., Duelli, P., Mueller, C., Kleijn, D. and Schmid, B. (2007) The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. Journal of Applied Ecology, 44(4), 813-822. https://doi.org/10.1111/j.1365-2664.2007.01306.x

172 Anderson, Annette, Tim Carnus, Alvin J. Helden, Helen Sheridan and Gordon Purvis (2013) The influence of conservation field margins in intensively managed grazing land on communities of five arthropod trophic groups. Insect Conservation and Diversity (2013) 6, 201–211 https://doi.org/10.1111/j.1752-4598.2012.00203.x

175 Dramstad, W.E., M. Sundli Tveit, W.J. Fjellstad and G.L.A. Fry (2006) Relationships between visual landscape preferences and map-based indicators of landscape structure. Landscape and Urban Planning. 76: 465-474. https://doi.org/10.1016/j.landurbplan.2005.12.006

198 Oelmann, Y., Buchmann, N., Gleixner, G., et al. (2011) Plant diversity effects on aboveground and belowground N pools in temperate grassland ecosystems: Development in the first 5 years after establishment. Global Biogeochemical Cycles, 25. https://doi.org/10.1029/2010gb003869

205 Lana-Renault, N., E. Nadal-Romero, M. P. Serrano-Muela, B. Alvera, P. Sánchez-Navarrete, Y. Sanjuan and J. M. García-Ruiz (2014) Comparative analysis of the response of various land covers to an exceptional rainfall event in the central Spanish Pyrenees, October 2012. Earth Surface Processes and Landforms 39, 581–592 https://doi.org/10.1002/esp.3465

215 S. Oreszczyn and A. Lane (2000) The meaning of hedgerows in the English landscape: Different stakeholder perspectives and the implications for future hedge management. Journal of Environmental Management. 59: 00-00. https://doi.org/10.1006/jema.2000.0365

242 Acreman M.C., Riddington R. & Booker D.J. (2003) Hydrological impacts of floodplain restoration: a case study of the River Cherwell, UK. Hydrology and Earth System Sciences, 7, 75-85. https://doi.org/10.5194/hess-7-75-2003

243 Fontaine, C., Dajoz, I., Meriguet, J. and Loreau, M. (2006) Functional diversity of plant-pollinator interaction webs enhances the persistence of plant communities. Plos Biology, 4(1), 129-135. https://doi.org/10.1371/journal.pbio.0040001

255 Acreman M. C., R. J. Harding, C. Lloyd, N. P. McNamara, J. O. Mountford, D. J.; Mould, B. V. Purse, M. S. Heard, C. J. Stratford & S. J. Dury (2011) Trade-off in ecosystem services of the Somerset Levels and moors wetlands. Hydrological Sciences Journal, 56, 8, 1543.

https://doi.org/10.1080/02626667.2011.629783

267 Morris, J, Hess, T.M., Gowing, D.J.G., Leeds-Harrison, P.B., Bannister, M., Vivash, R.M.N. and Wade. M. (2005) A framework for integrating flood defence and biodiversity in washlands in England. International Journal of River Basin Management, 3, 2, 105-115. https://doi.org/10.1080/15715124.2005.9635250

272 Batary, P., Baldi, A., Sarospataki, M., Kohler, F., Verhulst, J., Knop, E., Herzog, F. and Kleijn, D. (2010) Effect of conservation management on bees and insect-pollinated grassland plant communities in three European countries. Agriculture Ecosystems & Environment, 136(1-2), 35-39. https://doi.org/10.1016/j.agee.2009.11.004

279 Cosandey C., Andreassian V., Martin C., Didon-Lescot J.F., Lavabre J., Folton N., Mathys N. & Richard D. (2005) The hydrological impact of the mediterranean forest: a review of French research. Journal of Hydrology, 301, 4, 235-249. https://doi.org/10.1016/j.jhydrol.2004.06.040

282 Bautista, S., A. G. Mayor, J. Bourakhouadar and J. Bellot (2007) Plant spatial pattern predicts hillslope semiarid runoff and erosion in a Mediterranean landscape. Ecosystems 10: 987-998 https://doi.org/10.1007/s10021-007-9074-3

368 Beier, Claus, Bridget A. Emmett, Albert Tietema, Inger K. Schmidt, Josep Penuelas, Edit Kovacs Lang, Pierpaolo Duce, Paolo De Angelis, Antonie Gorissen, Marc Estiarte, Giovanbattista D. de Dato, Alwyn Sowerby, Gyorgy Kroel-Dulay,; Eszter Lellei-Kovacs,6 (2009) Carbon and nitrogen balances for six shrublands across Europe. Global Biogechemical Cycles, 23, GB4008. https://doi.org/10.1029/2008GB003381

375 Scholz, M., A. J. Sadowski, Harrington, R., et al. (2007) Integrated Constructed Wetlands assessment and design for phosphate removal. Biosystems Engineering 97(3): 415-423. https://doi.org/10.1016/j.biosystemseng.2007.03.021

414 Pardini, G., M. Gispert and G. Dunjo (2003) Runoff erosion and nutrient depletion in five Mediterranean soils of NE Spain under different land use. Science of the Total Environment 309: 213-224 https://doi.org/10.1016/S0048-9697(03)00007-X

445 Cammeraat, ELH (2004) Scale dependent thresholds in hydrological and erosion response of a semi-arid catchment in southeast Spain. Agriculture Ecosystems & Environment Volume: 104 Issue: 2 Pages: 317-332 https://doi.org/10.1016/j.agee.2004.01.032

466 P. Lindemann-Matthies, R. Briegel, B. Schüpbach and X. Junge (2010) Aesthetic preference for a Swiss alpine landscape: The impact of different agricultural land-use with different biodiversity. Landscape and Urban Planning. 98: 99-109. https://doi.org/10.1016/j.biocon.2009.10.003

470 van Berkel, D & Peter H. Verburg (2014) Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. Ecological Indicators 37: 163– 174 https://doi.org/10.1016/j.ecolind.2012.06.025

486 Emran M., Gispert M. & Pardini G. (2012) Comparing measurements methods of carbon dioxide fluxes in a soil sequence under land use and cover change in North Eastern Spain.

Geoderma, 170, 176-185. https://doi.org/10.1016/j.geoderma.2011.11.013

507 Persiani, O.M., Maggi, O., Montalvo, J., Casado, M.A. and Pineda, F.D. (2008) Mediterranean grassland soil fungi: Patterns of biodiversity, functional redundancy and soil carbon storage. Plant Biosystems, 142, 1, 111-119. https://doi.org/10.1080/11263500701872713

525 Lapointe, N. W. R., S. J. Cooke, J. G. Imhof, D. Boisclair, J. M. Casselman, R. A. Curry, O. E. Langer, R. L. McLaughlin, C. K. Minns, J. R. Post, M. Power, J. B. Rasmussen, J. D. Reynolds, J. S. Richardson and W. M. Tonn (2014) Principles for ensuring healthy and productive freshwater ecosystems that support sustainable fisheries. Environmental Reviews 22: 110-134 https://doi.org/10.1139/er-2013-0038

557 Lavorel,S. & Grigulis, K. (2012) How fundamental plant functional trait relationships scale-up to trade-offs and synergies in ecosystem services. Journal of Ecology, 100: 128-140. https://doi.org/10.1111/j.1365-2745.2011.01914.x

571 de Baets, S., J. Poesen, B. Reubens, B. Muys, J. De Baerdemaeker and J. Meersmans; (2009) Methodological framework to select plant species for controlling rill and gully erosion: application to a Mediterranean ecosystem. Earth Surface Processes and Landforms 34: 1374-1392 https://doi.org/10.1002/esp.1826

642 Maetens, W., Vanmaercke, M., Poesen, J., Jankauskas, B., Jankauskiene, G., Ionita, I., (2012) Effects of land use on annual runoff and soil loss in Europe and the Mediterranean. A meta-analysis of plot data.. Progress in Physical Geography 36(5): 597 - 651. https://doi.org/10.1177/0309133312451303

704 Christen, Benjamin and Tommy Dalgaard (2013) Buffers for biomass production in temperate European agriculture: A review and synthesis on function, ecosystem services and implementation. Biomass and bioenergy 55: 53-67 https://doi.org/10.1016/j.biombioe.2012.09.053

Czúcz, B., Götzl, M., Schwaiger, E., Sonderegger, G., & Schwarzl, B. (2017). Working paper on functional relationships between ecosystem characteristics and services in support of condition assessments. ETC/BD Working Paper https://bd.eionet.europa.eu/Reports/ETCBDTechnicalWorkingpapers/Functional_relationships_ecosystem_condition_assessments

Smith, A. C., Harrison, P. A., Pérez Soba, M., Archaux, F., Blicharska, M., Egoh, B. N., … Wyllie de Echeverria, V. (2017). How natural capital delivers ecosystem services: A typology derived from a systematic review. Ecosystem Services, 26, 111-126.

Annex 2: Annotated list of potential MAES ecosystem condition indicators

Table A2: This table lists all potential wetland condition indicators that are available and/or feasible in the context of the EU MAES assessment. All indicators are scored according to three aspects of 'usefulness':

- **rel**: relevance for wetlands (1: relevant, 2: slightly/indirectly relevant);
- **rep**: the degree to which the indicator represents the underlying condition aspect (1: good representation, e.g. indicator fully covers a major aspect → 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));

Relevance (rel), representativeness (rep), and availability (ava) are highlighted with a colour scheme following that of the 2nd MAES report (Maes et al., 2014). The overall 'usefulness' of each indicator (the coloured numbers in Tables 5.1 & 6.1) is calculated as the maximum (=worst) of these three scores. 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	rel	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	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	1	2	*Red List Index of threatened species*	SEBI 002	EEA, IUCN	index	afn	1980s 2004, ...?	**EU (MS?)**	EEA39

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	1	2	2	Living Planet Index for Mediterranean wetlands		WWF	index	n	1970-2005	**MS**	Mediterr countries
	1	1	2	Invasive alien species (richness)	SEBI 010	JRC-EASIN	1/area	f	?	10km	EU+
	1	1	3	Species diversity, richness (number and abundance of species, including vascular plants, vertebrates, etc)			index	f	?	?	?
				plants							
	1	3	3	Plant functional types (diversity)			?	f	?	?	?
	2	3	3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)			?	f	?	?	?
				birds							
	1	2	2	EU Population status and trends of bird species (%)	SEBI 003	Art12 DB	index	afn	2013, 2018	**MS**	EU
	1	2	1	*Bird indices (farmland, forest...)*	SEBI 001	EBCC	index	afn	2002-	**MS**	EU
				insects							
	2	2	2	Grassland Butterfly Indicator	SEBI 001	EEA	index	a	1990-2015	**MS**	22 MS
				habitats							
	1	1	2	*Conservation status and trends of habitats of community interest*	SEBI 005	Art17 DB	%	afn	2013, 2018	**MS x BGR**	EU
	1	2	2	*Threatened habitat cover*		Art17 DB	%	fn	2013, 2018	**MS x BGR**	EU
	1	1	1	Naturalness (index or typology)			index	f	?	?	?
	1	2	2	Red List Index of threatened habitats		IUCN EU RL	index	f	2017	?	?
	1	1	1	*Ecological status of surface water bodies*	SEBI 016	WISE	index		1992-	RBMP	EU
				Biomass at the site							
	1	1	1	Normalized difference vegetation index (NDVI)		Copernicus	index	f	1998-	1km	Global
	1	1	1	Leaf Area Index (LAI)		Copernicus	index	f	1998-	1km	Global
				Site structure							
	1	1	1	Structural heterogeneity		JRC	index	f	2006	250m	EU27
				Water availability							
	1	1	1	**Water and wetness probability index (WWPI)**		Copernicus	%		2009-	100m	EEA39
	1	1	1	**Normalized difference water index (NDWI)**		JRC	index		?	1km	Europe
	1	1	3	**Water levels**		?	?		?	?	?
	1	1	2	**Washlands (regularly flooded areas)**		ETM, DEM, ?	binary		2012	?	?
				The extent (abundance) of a specific subtype (of the target ecosystem type)							
	1	1	1	Extent of ETM subtypes	SEBI 004	CLC	%		1985-	100m	EU27
	2	1	1	Density of embedded seminatural elements (hedgerows, lines of trees, etc.)		JRC	%	a	2006	1km	EU27
	2	1	1	HNV area		JRC	%	a	2000, 2006	100m	EU27
				The coexistence / proximity of two different ecosystem types							

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	1	2	1	Proximity to water		ETM	km (or m)		2012	?	EU28+, TR, W. Balkan
				Landscape diversity							
	1	1	1	Landscape diversity		ETM	index		2012	?	EU28+, TR, W. Balkan
				Landscape fragmentation & connectivity							
	2	1	2	Landscape fragmentation from urban and transport infrastructure	LSI 004, CSI 054	EEA	km2	af	2012	1km	EU28+, TR, W. Balkan
	1	1	1	Fragmentation patterns of natural/seminatural landscapes	SEBI 013	CLC (ETM?)	index	fn	2006-2012	100m	EEA39
	1	3	1	Wetland connectivity		ETC/SIA	index	n	2014	Link	EU27+, TR
				Management / disturbance intensity (pressures)							
				All ecosystems and land uses							
O	1	1	1	**Hemeroby**		CLC, CAPRI, AFOLU			2006	100m	EU27
				Farming intensity							
OP	2	1	1	Intensification / extensification	AEI12	Euro-stat	index (EUR)	an	1996, 2006	NUTS2	EU 27
OP	2	2	1	Mineral fertilizer consumption	~SEBI 019, AEI5	CAPRI	kg/ha/y	a	2000-2015	NUTS2	EU28
P	2	2	1	Pesticide use	AEI06	Euro-stat	kg/ha/y of act. ingred	a	2011-2014	**MS**	EU28
	2	2	1	Water abstraction	AEI20	JRC?	10^6 m3/y	a	2006	5km	some MS
OP	2	1	1	Share of organic farming	SEBI 020, AEI4	FSS	%	a	2005, 2012-2016	**MS**	EU28
				Grazing intensity							
O	2	1	1	Livestock density		FSS, CAPRI	LU/ha	a	2010, 2012	5km, HSU(?)	EU28
				Nutrient / material balances							
OP	1	1	1	Gross nitrogen balance	~SEBI 019, AEI15	CAPRI	kg/ha/y	a	1990-	1km (HSU)	EU28
P	1	1	1	Nitrogen deposition		IMAP, LRTAP	kg/ha/y	af	2005	5km	EU
P	1	1	1	*Critical load exceedance for nitrogen*	SEBI 009	EEA	% of nat. area	n	2000, 2010	50km	EU27+
OP	1	1	1	Gross phosphorus balance	AEI16	CAPRI	kg/ha/y of P	a	1990-2016	**MS**	EU
P	2	1	2	Acidification	IND-30, CSI 005, AIR 004	JRC	kg/ha/y of S	f	?	?	?
P	1	1	1	*Chemical status of surface/ground water*	SEBI 016	WISE	index	a	1992-	RBMP	EU

References

Maes J, Teller A, Erhard M, Murphy P, Paracchini ML, Barredo JI, … Lavalle C (2014). Mapping and Assessment of Ecosystems and their Services: Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. 2nd Report. Publications office of the European Union, Luxembourg. http://catalogue.biodiversity.europa.eu/uploads/document/file/1230/2ndMAESWorkingPaper.pdf

Maes J, Teller A, Erhard M, Grizzetti B, Barredo JI, Paracchini ML, … Werner B (2018). Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition. Publications office of the European Union, Luxembourg. https://biodiversity.europa.eu/maes

Annex 3: 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 (ES): 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 (ET): 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.

References

CBD, 1992.Convention on Biological Diversity. United Nations.

Czúcz, B., Condé, S. (2017). Note on definitions related to ecosystem conditions and their services based on different glossaries. ETC/BD Technical Paper. https://bd.eionet.europa.eu/Reports/ETCBDTechnicalWorkingpapers/Definitions_ecosystem_conditions_and_services

EEC, 1992. Council directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

MA, 2005. Ecosystems and Human Wellbeing: Current State and Trends, Volume 1, Island Press, Washington D.C.

Maes J, Teller A, Erhard M, Grizzetti B, Barredo JI, Paracchini ML, … Werner B (2018). Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition. Publications office of the European Union, Luxembourg. Will be available from: https://biodiversity.europa.eu/maes

OpenNESS, 2014. OpenNESS Glossary (V2.0). Grant Agreement No 308428. Available from: http://www.openness-project.eu/library/reference-book

OECD, 2016. Glossary of statistical terms. http://stats.oecd.org/glossary/

Parson, E.A., 1995. Integrated Assessment and Environmental Policy Making, in Pursuit of Usefulness, Energy Policy, 23(4/5), 463–476.

SEEA-EEA, 2012. System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting. http://unstats.un.org/unsd/envaccounting/eea_white_cover.pdf

Smith, A. C., Harrison, P. A., Pérez Soba, M., Archaux, F., Blicharska, M., Egoh, B. N., … Wyllie de Echeverria, V. (2017). How natural capital delivers ecosystem services: A typology derived from a systematic review. Ecosystem Services, 26, 111–126.

TEEB, 2010. The Economics of Ecosystems and Biodiversity: Ecological and economic foundation. Earthscan, Cambridge.

UK NEA, 2011. The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge

Annex 4: List of abbreviations

AEI	agri-environmental indicator
AFOLU	agriculture, forestry and other land use
Art17 DB	Article 17 (assessments of habitats and species under the EU Habitats Directive)
Art12 DB	Article 12 (assessments of species under the EU Birds Directive)
BGR	biogeographic region
CAPRI	Common Agricultural Policy Regionalised Impact
CBD	Convention of Biological Diversity
CLC	Corine land cover
Copernicus	the Earth observation programme of the European Commission
Corine	Coordination of Information on the Environment
DB	database
DEM	digital elevation model
DNA	deoxyribonucleic acid
EBCC	European Bird Census Council
EEA	European Environment Agency
EEC	European Economic Community
ES	ecosystem service(s)
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	ecosystem type map
EU	European Union
EUNIS	European Union Nature Information System
Eurostat	the statistical office of the European Union
FSS	farm structure surveys
HANPP	human appropriation of net primary production
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)
IMAP	Integrated Monitoring and Assessment Programme
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
EASIN	European Alien Species Information Network
EFFIS	European Forest Fire Information System
KIP INCA	Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting
LAI	Leaf Area Index
LoCo	local component (of Copernicus)
LRTAP	Long Range Transfer of Air Pollution
LU	livestock units
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
N2000	Natura 2000 (network of nature protection areas in the European Union)
NDVI	normalized difference vegetation index
NPP	net primary production
NUTS	nomenclature of territorial units for statistics
OpenNESS	Operationalisation of natural capital and ecosystem services (EU FP7 project)
potNatVeg	potential natural vegetation
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
UK NEA	UK National Ecosystem Assessment