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Ecosystem service fact sheet on flood regulation

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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 flood regulation is defined, which characteristics of the various ecosystem types are relevant for flood regulation, and what kind of indicators are available for these characteristics. A discussion on the options for improving the integration of condition indicators into ecosystem service modelling is particularly relevant for ensuring coherence between the different components of the EU MAES assessment. The fact sheet is concluded by a set of annexes, which contain all relevant metadata behind the whole analysis.

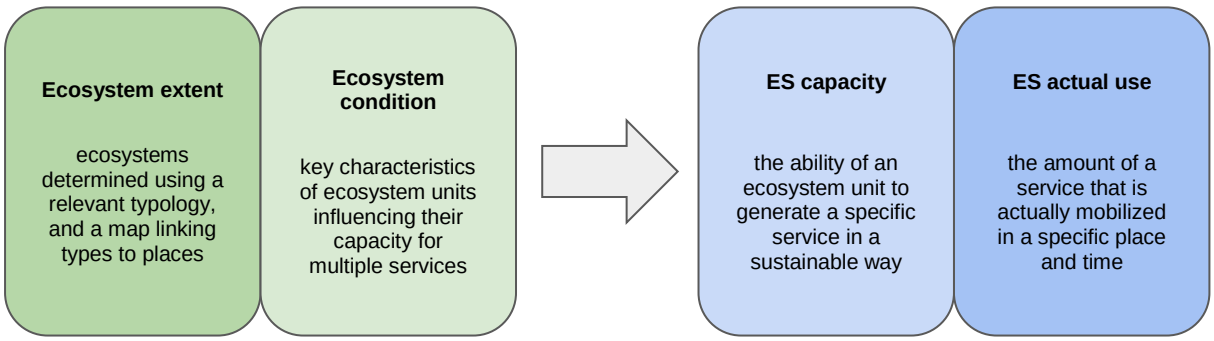

Figure 1.1: A simplified representation of the MAES conceptual framework (based on Maes et al., 2014; Burkhard et al., 2018; and MAES-INCA, 2018). The four boxes describe the main elements which need to be quantified (mapped and assessed) during the EU MAES assessment process.

2. Key messages

A flood is an overflow of water on land which is usually dry. There are two main types of floods, that are fundamentally different in their causes and mechanisms: coastal and riverine floods. In this fact sheet only **riverine floods** are considered. Nature can help to mitigate riverine floods in essentially two ways:

- it can prevent flood waves 'at the start' by retaining water where it falls down (**water retention**), and
- it can provide space for rivers to spread out in the lower basins, thus reducing flood waves (**peak flow reduction**).

As these mechanisms are highly different, they are considered as two different ES "subtypes" of the ES of (riverine) flood regulation. It is important to note, that the *water retention* subtype, as a 'preventive' mechanism is much more indirect, but also much more efficient, than the *peak flow reduction* subtype, which just aims at 'post-hoc mitigation'. The relevant characteristics of the ecosystems, which influence the availability of these two subtypes are also highly different:

- *Water retention* is most influenced by the amount and stability of vegetation biomass / cover, and relatedly the age of ecosystems, and the management activities perturbing the continuity of the vegetation cover. The biophysical characteristics of the ecosystems are crucial in determining their capacity to provide this subtype of the service.
- In *peak flow reduction* the main role of ecosystems is to provide storage space for excess water. The process is primarily influenced by the geometry of the river and the basin (like small slopes in the floodplain) and ecosystem characteristics play a relatively minor but complex role (e.g. through altering surface roughness or storage capacities).

Both mechanisms of natural flood regulation are similar, however, that the service provisioning areas (source ecosystems) are not the same as the locations which benefit from the service (service beneficiary areas). It is the characteristics of the service provisioning areas that are relevant for both subtypes of the service (Fig. 2.1). The most important indicators that can potentially be used to characterize *water retention* are the following:

- Yearly statistics (minima and means) of the **normalized difference vegetation index** (NDVI) (or other similar remote-sensing based biomass indicators) is a relatively mature and accessible option to efficiently characterize the capacity of vegetation cover to slow down the passage of water.
- **Tree cover density** can be another relevant option, particularly in non-forested ecosystem types.
- **Imperviousness**, i.e. the share of paved surfaces is a closely related important indicator, in particular for urban ecosystems (on the contrary to forests where imperviousness is typically low).
- The **length of the felling cycle** (or the closely similar *long term ratio of annual fellings to net annual increment*) can be an important management indicator determining the capacity of forests for *water retention*. The **age of the forests** can be a similarly good simple indicator.
- The general land use intensity of the landscapes could be described by a simple "**hemeroby**" indicator, which could be relatively easily computed from the European ecosystem type map

(ETM v3.1; Weiss & Banko, 2018) with an expert scoring. Hemeroby can be relevant for *water retention* (and a number of other ES).

- And as fire is a disturbance that can critically influence the passage of runoff water, the **frequency of wildfires** is a further potential condition indicator relevant for flood control.

There are very few ecological / biophysical indicators that can be considered as relevant for *peak flow reduction*, which is much more governed by the local geometry of streams, rivers and floodplains.[1] Nevertheless, there is one potential key indicator, which might be useful in the context of the EU MAES assessment, if it will be implemented:

- the presence/availability (share) of freely floodable adjacent (semi)natural ecosystems (often called **washlands**) could be used as a new indicator, which can be an efficient simple proxy for the role that lowland ecosystems (wetlands, grasslands, adequately managed croplands, etc.) can have in mitigating flood waves in adjacent streams and rivers.

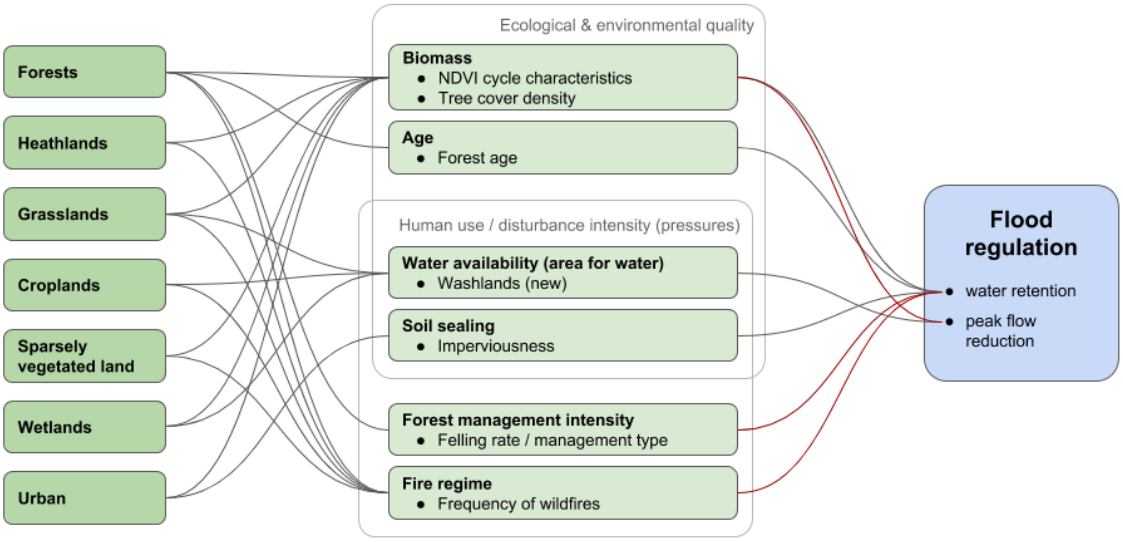

Figure 2.1: A graphical summary of this fact sheet. *Ecosystem types* (column 1) are connected to their *relevant characteristics* ('condition aspects'; column 2) and a possible set of *key indicators* (bullet points in column 2), which determine their *capacity for flood regulation* (column 3). Characteristics not connected to any ecosystem type are landscape-level characteristics. 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.

[1] The underlying systematic review, as well as the subsequent indicator analysis focussed on the terrestrial ecosystem types, so river morphological characteristics (e.g. curve number) that are potentially also relevant for posterior peak flow reduction (e.g. through the speed of river discharge) were not considered.

3. Flood regulation as an ecosystem service

A flood can be loosely defined as the discharge of a river which exceeds bankfull limitations. Such rise of the water level is considered a temporary event and can occur in creeks, rivers, canals, lakes, along the seacoast, or within wetlands. This results in spilling over and out of the natural or artificial confines which has considerable impacts onto land which is normally dry (Tochner et al., 2009). The consequences of floods, can be both negative and positive, and can vary greatly depending on the location, duration, depth and speed of the flooding events, as well as the vulnerability and the economic value of the locations they affect. Such impacts may include social, economical and environmental disruptions. Due to population growth, land development, river straightening, land management, consumption and conversion of land, the potential damages caused by floods are increasing. Demand for flood regulation is greatest in highly populated lowland areas (Sauter, et al, 2018), where the eventual benefit of flood regulation is the protection of human lives, health, and properties (Nedkov et al., 2012).

Floods can develop in many ways. The most common is when creeks, rivers or canals overflow their banks following a heavy rainfall, rapid icemelt, and/or the failure of human infrastructure (e.g. dams reservoirs). These floods are called *riverine floods*.[2] *Coastal floods* (including estuarine flooding) happen when a large storm or a tsunami causes the sea level to rise and seawater to rush inland. As coastal and riverine floods are fundamentally different both in terms of their ecological mitigation mechanisms, and the participating ecosystem types, they are very rarely assessed together, thus being practically considered as different ecosystem services. This fact sheet only focuses at the regulation of **riverine floods** (including canals, lakes, wetlands, or other 'freshwater floods'), and coastal (or estuarine) floods are not considered. This choice is highly in line with the focus of the systematic review underlying this fact sheet.

As an ecosystem service 'flood regulation' comprises all kinds of potential contributions that (semi)natural ecosystems can give to reducing flood risks in flood-prone areas. The contributing ecosystem does not necessarily need to be the 'local' ecosystem (the one which is being protected) – on the contrary, flood regulation typically happens far away from the target locations, either 'upstream' or 'downstream' along the water path. Thus, the source ecosystems ('service provisioning areas' sensu Syrbe & Walz, 2012) which provide the ES of flood regulation are typically distinct from the 'service beneficiary areas' which enjoy the benefits of the ES.[3] 'On-site' possibilities for 'nature-based' flood protection are typically very limited.[4] The connection between the source ecosystems and the beneficiary areas is directional, and is mediated by hydraulic flows governed by surface geometry (Fisher et al., 2009).

Based on the way how ecosystems interact with the runoff process, a further important distinction can be made. The first point where terrestrial ecosystems can interact with the runoff process is when the rain (or snow) reaches the surface. At this point the local ecosystem can provide considerable incipient flood prevention by **water retention**. Vegetation can retain a high amount of water through interception by leaves, canopy and litter, thus reducing the amount of precipitation reaching their soil surface to a considerable degree (EEA 2015), while litter as well as roots increase infiltration into the soil and thereby reduce surface runoff in quantity and speed, prior to the

[2] The third type of floods sometimes mentioned in the literature, *pluvial* or *flash floods* can be treated as special cases of the riverine floods in the upper portion of stream catchments.

[3] This creates additional complexities for ES mapping: at which place the ES should be mapped? If the main purpose of the mapping is to highlight / compare the services provided by the different ecosystems, then the good choice is probably to map the ES at their source ecosystems.

[4] In contrast with flood regulation as an ES, most of the engineering solutions for flood control typically focus at the sites that need to be protected (thus offering 'end of pipe' solutions).

accumulation of a flood wave (Zhang et al., 2014). Later on, when the water gets into streams and rivers (or wetlands and lakes) only the ecosystems adjacent to these downstream water bodies can interact with the runoff, and only in a much more limited way (**peak flow reduction**). In this case the most typical beneficial interaction is that these adjacent ecosystems offer "space" (storage capacity) for the floodwater, thus reducing the height (and thus the severity) of the flood wave.

Both *water retention* and *peak flow reduction* processes contribute to the reduction of flood risks through a reduction of peak water levels in the rivers. Nevertheless, the underlying mechanisms are very different in the two cases, and consequently the characteristics (=condition aspects) of the source ecosystems (service provisioning areas) that determine the 'efficiency' of flood regulation will also be very different. For *water retention* the structural characteristics of the source ecosystems (e.g. vegetation and surface texture) are of key importance, determining the capacity of the local ecosystem to retain some water and slow down runoff. On the other hand, *peak flow reduction* is primarily governed by the geometrical / morphological characteristics of the broader riverbed, thus it is much less affected by the ecological or biophysical characteristics of the ecosystems themselves. Based on this fundamental difference, *water retention* and *peak flow reduction* will be clearly distinguished in the following discussion as *two "subtypes" of the studied ES*.

Water retention is relevant in all terrestrial ecosystem types (highly depending on their characteristics), whereas *peak flow reduction* only involves, rivers, lakes, wetlands and low-lying terrestrial ecosystems adjacent to them. Accordingly, the indirect mechanism of *water retention* is much more widespread (and probably also significantly more efficient than the 'post-hoc' mitigation through *peak flow reduction* of the service) – thus being probably the most important 'leverage point' in the runoff process, where natural ecosystems can most efficiently prevent subsequent floods in typically distant locations.

Despite the differences of the underlying mechanisms and contributing ecosystems, most of the widespread ES classifications do not distinguish even coastal and riverine floods consistently, and they have even less consideration for the subtle distinction between the incipient (*water retention*) and posterior (*peak flow reduction*) contributions of natural ecosystems in the case of riverine floods (Table 3.1). TEEB does not make any distinction at all, whereas CICES introduces a slight distinction into the name of its class 2.2.1.3 by naming "flood control" and "coastal protection" as two 'subtypes' of this service.[5] In IPBES taxonomy flood control is split across two NCPs: NCP 6 clearly focuses on riverine flood regulation by *water retention*, while NCP 9 seems to merge riverine *peak flow reduction* with *coastal* flood regulation.[6]

The fact that TEEB (and partly also CICES) seem to be insensitive to these differences in the underlying regulation processes might be due to categorizing the ES from the beneficiaries' perspective. From this perspective all these cases appear as the same type of 'water damage' (avoided or not), with essentially the same economic and social consequences. However, if the contribution of natural systems is expected to be assessed or mapped, these underlying subtypes, that have been elaborated so far, will become very relevant: it is impossible to consistently measure/map nature's contributions to flood protection without distinguishing the main mechanisms of contribution.

[5] In the previous version of CICES (v4.3), there was a different type of distinction made, very similar to that of IPBES: class 2.2.2.1 covered 'hydrological cycle and water flow maintenance', and 2.2.2.2 covered 'flood protection' (including coastal floods).

[6] In addition to its peak flow regulation aspects, NCP 6 (as well as the old CICES v4.3 class 2.2.2.1) relates to the maintenance of baseline flows in dry periods ('drought mitigation'). Even though this can be conceptualized as a different benefit / ES, the underlying mechanism (water retention) is the same.

Table 3.1: The position of flood regulation in CICES (v5.1, Haines-Young & Potschin, 2018) and other major ES classification systems (IPBES: Pascual et al., 2017; TEEB, 2010; MA, 2005)

	CICES v5.1	Other classifications
Classification	**Section: 2** Regulation & Maintenance (Biotic) **Division: 2.2** Regulation of physical, chemical, biological conditions **Group: 2.2.1** Regulation of baseline flows and extreme events **Class: 2.2.1.3** Hydrological cycle and water flow regulation (including flood control, and coastal protection)	**IPBES**: ● **NCP 6**: Regulation of freshwater quantity, location and timing ● **NCP 9**: Regulation of hazards and extreme events **TEEB**: Moderation of extreme events **MA**: Natural hazard regulation (partly)
Definition	**Scientific**: The regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems that assists people in managing and using hydrological systems, and mitigates or prevents potential damage to human use, health or safety **Simple**: Regulating the flows of water in our environment	**IPBES**: NCP 6: Regulation, by ecosystems, of the quantity, location and timing of the flow of surface and groundwater (...). Regulation of flow to water-dependent natural habitats that in turn positively or negatively affect people downstream, including via flooding (wetlands incl. ponds, rivers, lakes, swamps). (...) NCP 9: Amelioration, by ecosystems, of the impacts on humans or their infrastructure caused by e.g. floods, wind, storms, hurricanes, seawater intrusion, tidal waves, heat waves, tsunamis, high noise levels **TEEB**: Extreme weather events or natural hazards include floods, storms, tsunamis, avalanches and landslides. Ecosystems and living organisms create buffers against natural disasters, thereby preventing possible damage. (...)
Example for service	The capacity of vegetation to retain water and release it slowly (...)	
Example for benefits	Mitigation of damage as a result of reduced in magnitude and frequency of flood/storm events	

4. Ecosystem characteristics influencing the supply of flood regulation

From the 10 papers studied in the systematic review underlying this report (Czúcz et al., 2018) seven papers were related to *water retention*, whereas 3 were related to *peak flow reduction*. Tables 4.1 and 4.2 provide an overview on the characteristics of the main ecosystem types that were found to influence these two subtypes of flood regulation, respectively. According to the scientific literature sampled in the underlying systematic review, the most relevant characteristics influencing the *incipient* ES are biomass and the intensity of land management, whereas *peak flow reduction* is most influenced by the opportunities for stream/river water to spread out (presence & water storage capacity of wetlands, or other floodable adjacent ecosystem types). It is important to note, however, that there were very few papers in the systematic review, which focussed on *peak flow reduction* (and the connected downstream ecosystems) in this context, and neither the morphological characteristics of the riverbeds, nor the factors governing the speed of runoff were adequately explored.

Table 4.1: Results of the systematic review: ecosystem characteristics that have been documented to influence the supply of '*water retention*' (buffering water at the place of first contact, before it could accumulate in rivers), and the ecosystem types in which these relationships had been documented (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 flood regulation. A more detailed and fully referenced version of this table can be found in Annex 1.

Characteristics type	Total	Positive	Negative	Mixed	Ecosystem types
Biomass at the site	**4**	4	0	0	forest, grass, heath, SVL
total [cover]	**3**	3	0	0	grass, forest, heath, SVL
total [height]	**1**	1	0	0	heath
litter	**1**	1	0	0	heath
Management / disturbance intensity	**3**	0	3	0	forest, crop, grass, heath, SVL
fire frequency	**2**	0	2	0	forest, crop, grass, heath, SVL
clearcutting	**1**	0	1	0	forest
The extent (abundance) of the target ecosystem type (or a specific subtype)	**3**	3	0	0	forest, urban
forest (vs. open)	**2**	2	0	0	forest
urban green	**1**	1	0	0	urban
Age of site / community	**1**	1	0	0	forest
since cutting	**1**	1	0	0	forest

** MAES ecosystem types: crop: cropland; grass: grassland; forest: woodland and forest; heath: heathland and shrub; SVL: sparsely vegetated land; wet: wetlands*

Table 4.2: Results of the systematic review for '*peak flow reduction*' (mitigating flood waves in rivers and streams). Further details above at Table 4.1.

Characteristics type	Total	Positive	Negative	Mixed	Ecosystem types
Water availability	**4**	3	1	0	crop, grass, wet, water
washland (regularly flooded land)	**3**	3	0	0	crop, grass, wet
water levels	**1**	0	1	0	wet, water
Biomass at the site	**1**	0	1	0	wet
total [height]	**1**	0	1	0	wet

** MAES ecosystem types: crop: cropland; grass: grassland; wet: wetlands; water: rivers and lakes*

Biomass as a structural element of ecosystems, plays the most important role for supplying *water retention*. Lana-Renault et al. (2014) examined different types of land cover (subhumid badlands, dense forest, abandoned farmland area recolonized by shrubs and forest patches and subalpine grassland) during heavy rainfalls. They emphasize that vegetation cover is a major factor affecting

the control of floods. This is being confirmed by Cosandey et al (2005) based on their analysis of forests and the increase of extreme floods: vegetated or bare soil is far more responsible for mitigating floods than the state of the forests per se. Simulating surface water runoff by modelling rainfall and slope lead to much better values when adding vegetation cover to this model (Schmittner et al., 1996). Different forest types and changes in forest cover also lead to different effects on flows (Robinson et al., 2003). In an urban context the amount of biomass, or even just green surfaces also plays a similarly important role (Stovin et al., 2012). Additionally, a healthy porous **soil** (with high organic carbon content) can hold more water and enhance evapotranspiration, thus both delaying and reducing runoff (Nepstad et al., 1994). The factors governing the speed of runoff at a given site are also summarized by Chow (1964; see also Burkhard & Maes 2017).

Human **management** activities and natural **disturbances** are further important factors influencing the flood regime of watersheds. Clearcutting or fire events, for example, have dramatic consequences on the capacities of natural ecosystems to slow down runoff (*water retention*). Clearcutting can be particularly detrimental, if all the plant residues (felling debris) are also removed (Robinson et al., 2003). Wildfires can have very similar effects, but depending on the size of the area burnt there is a threshold value below which there are no changes in hydrological behaviour (Aronica et al., 2002). Clearcutting and wildfires adversely influence the supply of flood regulation addressing *water retention* (Robinson et al., 2003; Aronica et al., 2002).

In terms of *peak flow reduction*, the presence of floodable ecosystems seems to be a key factor, with **wetlands** being the ideal ecosystem type for temporary flood water storage (Acreman et al., 2003, 2011). The storage capacity of wetlands, nevertheless, depends on the degree to which their water levels are allowed to fluctuate (Acreman et al., 2011), so “stable” wetlands habitat types can be less useful in this respect, than highly fluctuating “temporary” marshes. Other ecosystem types in the geomorphological river floodplains can also be useful for temporary flooding: such grasslands, agricultural fields, etc. are often called **washlands** (Morris et al., 2005; Acreman et al., 2011). Restoring wetlands and washlands in floodplains tends to be profitable, referring to historical wet floodplain pastures (Acreman et al., 2011).

In contrast with *water retention*, the presence of **biomass** seems to be disadvantageous for *peak flow reduction*, as high vegetation increases floodplain roughness, and slows down runoff (Morris et al., 2005). There might be many other **morphological factors** of the river and the floodplain that might influence the discharge of river flood waves, which were not found due to the low number of papers reviewed. Nevertheless, these morphologic characteristics are primarily abiotic nature, and the underlying hydraulic processes are spatially highly complex (quick runoff from one segment of the floodplain can lead to an increased flood risk in another segment). Accordingly, these unexplored morphological characteristics are probably highly context-dependent, and thus they are less relevant as simple and universal ecosystem condition indicators.

5. Ecosystem condition indicators relevant for flood regulation

The ecosystem characteristics listed in the previous chapter (Tables 4.1 & 4.2) are not independent from each other. Thus not all of the identified / proposed aspects need to be covered by an ideal indicator system in order to be relatively comprehensive, and a focus on 'low hanging fruits' (aspects for which there are better / more readily available data) can be justified. Table 5.1 & Annex 2 provide overview of the potential condition indicators and their underlying data sources for each of the condition aspects listed in Tables 4.1 & 4.2, 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 flood regulation. The 'usefulness' of each indicator is highlighted with a 'traffic lights' colour scheme.* Proposed **key indicators** are highlighted in bold.

U*	Indicator name	Comments
	Age of site / community	
2	**Forest age (% of forest in age categories)**	this could be a conceptually important indicator, still needs to be developed
3	Community age (time since last major intervention/ disturbance: felling, fire, abandonment, etc)	this could be conceptually important, feasibility on a remote sensing basis should be tested
	Biomass at the site	
1	**Normalized difference vegetation index (NDVI)**	instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators; is positively related to water retention (upstream / mountain) but negatively / complexly to peak flow reduction (downstream / floodplain); a single biomass indicator can be enough
1	Leaf Area Index (LAI)	see above
2	Biomass volume (growing stock)	only available at a very coarse spatial resolution
2	Carbon stock	
2	Tree height	
2	**Tree cover density**	can be important for water retention in mountain ecosystems (but negatively / complexly related to peak flow reduction in downstream / floodplain contexts)
3	Tree crown size (diameter)	
3	Canopy volume (from remote sensing)	
	Site structure	
2	Structural heterogeneity	
	Water availability	
2	Water and wetness probability index (WWPI)	wetlands with a low/fluctuating water level can offer more storage space than ones with stable water levels (peak flow reduction)
3	Water levels	wetlands with a low/fluctuating water level can offer more storage space than ones with stable water levels (peak flow reduction), needs to be developed, data source unclear
2	**Washlands (regularly flooded areas)**	space for flood to spread out, conceptually important for peak flow reduction, needs 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.)
3	Extent of forest types	still under development (?)
1	Density of embedded seminatural elements (hedgerows, lines of trees, etc.)	seminatural elements can considerably slow down runoff
1	HNV area	the share of this highly relevant 'subtype' might be redundant with other indicators (seminatural elements, pressures, etc.)
	Landscape diversity	
2	Landscape diversity	can be relatively easily developed

** 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)*

Water retention is strongly determined by the aboveground **biomass** cover, and its fluctuations. Biomass and vegetation cover can be best characterized with remote-sensing based indicators. The *normalized difference vegetation Index* (NDVI) and *leaf area index* (LAI) are probably the most accessible proxies that can be used. Nevertheless, it is important to note that it is not so much the average, but rather the spatial and temporal fluctuations / minimum values (within a year or a management cycle) of these indices, which determines the efficiency of flood regulation, and this needs to be taken into consideration when raw (instantaneous) NDVI or LAI values are being aggregated for use as condition indicators. Similarly, *tree cover density* can also be a simple but important indicator, especially in the case of non-forest (e.g. urban) habitats. In forests, the *growing stock* indicator, one of the most basic statistics of any forest inventory, can be seen as a key indicator of biomass. The standing volume of growing stock can also be converted into estimates of above and below-ground woody biomass by applying biomass expansion factors (see SEBI 017).

Biomass can also partly be determined by land cover (habitat types and **subtypes**). The distinction between perennial crops (which are classified under forests and heathlands under ETM v3.1 – Weiss & Banko, 2018) and real forests and grasslands makes a key difference. Similarly, forest types, or the amount of semi-natural vegetation fragments embedded in croplands can be important indicators for *water retention*.

The **age** of forests and various other communities can also influence their capacity for slowing down runoff, and *water retention*. **Forest age** (e.g. as a % of forest in age categories) can potentially be extracted from forest inventory datasets, but this indicator is still under development (Maes et al., 2018). **Community age** (time since last major intervention/ disturbance: felling, fire, abandonment, etc.) could also be the basis for a highly relevant condition indicator, which could theoretically be derived from satellite time series. Nevertheless, there is no such indicator available yet, and its development would still demand a lot of efforts.

There is relatively little available information to characterise the *peak flow reduction* capacity of floodplain ecosystems. As a matter of fact, this process (the spread of flood in downstream basins) is principally governed by the geometry of the floodplain basins and the characteristics of the actual flood wave, so it does not really depend on the characteristics of the ecosystems. The only weak indicators available here are related to the **availability of "floodable space".** For stream and river basins the availability (share) of *washlands* (i.e. adjacent (semi)natural ecosystems, designated for floodwater storage) could be used as a new indicator, whereas for wetlands the 'evenness' of the *normalized difference water index* (NDWI) could be considered as an additional, remote sensing-based proxy. In the case of rivers and lakes the magnitude of their *littoral zones* can also be seen as an indirect proxy for this condition aspect, which can potentially also be derived from ETM v3.1.

6. Integrating pressures among condition indicators

The intensity (frequency or magnitude) of recurrent human management activities and/or (semi)natural disturbance regimes can be seen as characteristics of the ecosystems that highly influence their capacity 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 will be clustered according to the ecosystem types and their typical management activities/disturbance regimes instead of the HIPOC categories. From the HIPOC classes, *pollution* and *overexploitation* 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 ecosystem characteristics. *Habitat loss* has two important special cases: (1) when land is transformed to a different ecosystem type, and (2) processes 'internal' to a specific ecosystem type. Cases of (1) are best handled under the ecosystem extent 'box' of the MAES framework (Fig. 1.1), and replicating them under the ecosystem condition 'box' creates inconsistencies in the whole MAES assessment framework. However, processes that are (2) 'internal' to an ecosystem type, like soil sealing in the case of urban ecosystems, can be meaningfully represented as ecosystem condition, and they should be included here (Table 6.1).

General land use / management intensity indicators, which integrate various aspects of management intensity into a single overall indicator can be of key importance for *water retention*, as human management activities often speed up the passage of runoff water. Such indicators (e.g. *hemeroby, HANPP*), can perhaps best be implemented in a simple form relying on ETM 3.1 and an expert scores table. In the case of flood regulation, hemeroby plays a complex role: for *water retention*, an increased hemeroby of the 'upper catchments' can lead to a reduced ES through reduced *water retention* capacities. For rivers and floodplains, however, increased hemeroby has a controversial role as it can support artificial defence measures (e.g. dykes) or a reduced roughness from vegetation.

From the management, intensity indicators targeting specific ecosystem types are probably the ones related to ***forest*** *fellings*, which are most relevant from the perspective of *water retention*. The long term ratio of fellings to net annual increment is a key pressure indicator (see Table 6.1) of forest management sustainability. Unfortunately, this indicator is currently only available at a very coarse spatial resolution (MS level, SEBI 017).

In terms of agricultural areas, the *intensity of grazing* can be for **grasslands**, and the *intensification/extensification* of farming, and (in particular) the share of permanent crops or *fallows* can be relevant management indicators in **croplands**, influencing runoff and thus flood control.

Table 6.1: Indicators available for pressures relevant for flood regulation. The 'usefulness' of each indicator is highlighted with a 'traffic lights' colour scheme.* Proposed **key indicators** are highlighted in bold.

U*	Indicator name	Comments
	All ecosystems and land uses	
2	Hemeroby	a newly proposed condition indicator with a long history, conceptually close to "naturalness", still needs to be implemented
2	Human Appropriation of Net Primary Production (HANPP)	
	Farming intensity	
2	Intensification / extensification	only available at NUTS2 level
2	Share of fallow land	
	Grazing intensity	
2	Livestock density	(over)grazing reduces water retention capacities and speeds up runoff
	Forest use intensity	
2	Long term ratio of annual fellings to net annual increment	a key indicator for forest cover perennity/sustainability
2	**Length of the felling cycle**	a key indicator for forest cover sustainability
	Soil loss	
2	Soil erosion	indirectly, could also be seen as an ES indicator (for erosion control)
1	**Imperviousness**	the 'stock' of sealed surfaces (imperviousness) is much better to indicate condition than its change (soil sealing), related to both water retention (urban flash floods caused by increased runoff) and the demand for flood control
	Fire regime	
2	**Number of fires**	
2	Burnt area	slightly redundant w fire frequency

** 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)*

In **urban** areas the share of *sealed surfaces* (soil sealing, imperviousness) critically determines runoff, and thus local flood regimes. Soil sealing can be best addressed using the amount (share) of sealed surfaces. This can be seen as the underlying state variable of the pressure of soil sealing, and is available with high resolution from Copernicus under the name *imperviousness*.

As a relevant **disturbance**, fire regime can also critically influence *water retention* in all ecosystem types, and the *fire frequency* indicator generated from remote sensing data by the JRC can be a good indicator for this aspect of ecosystem condition.

There are no indicators in Table 6.1 that can be seen as relevant for *peak flow reduction*, and the reason for this is same as the one mentioned in the previous chapter: flood mitigation by letting the flood wave spread out is principally a physical process only affected by the geometry of the basin. The only management activities that can improve the capacity of ecosystems (=land) for excess flood water retention is to designate (and manage) them as washlands, and to keep them dry between floods (=low wetland water table levels, see Table 6.1), but these options have already been discussed in the previous chapter.

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Annex 1: The papers studied in the systematic review

Table A1: This table identifies the scientific papers related to the ES flood regulation, that were reanalysed from the OpenNESS systematic review (Smith et al., 2017). The table follows the structure of Tables 4.1 & 4.2, 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 characteristics for flood regulation:

- **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 specific MAES ecosystem types (urb: urban; cro: cropland; gra: grassland; for: woodland and forest; hea: heathland and shrub; SVL: sparsely vegetated land; wet: wetlands; wat: rivers and lakes). 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 paper are resolved in a reference list at the end of this Annex. Papers that study the *posterior subtype* of the service (242, 255, 267) are highlighted *in italics*.

Characteristics type	TT	NN	urb	cro	gra	for	hea	SVL	wet	wat
Management / disturbance intensity [T mi]	3	-3		119	279	119, 278, 279	119	119		
fire frequency	2	-2		119	279	119, 279	119	119		
clearcutting	1	-1				278				
Age of site / community [T ta]	1	1				278				
since cutting	1	1				278				
Biomass at the site [T bi]	5	3			205, 279	205, 278, 279	103, 205	205	*267*	
total [cover]	3	3			205, 279	205, 279	103, 205	205		
total [height]	2	0					103		*267*	
litter	1	1					103			
Water availability / quality [T wa]	4	2							*255*	*255*
washland (regularly flooded land)	3	3		*242, 255, 267*	*242, 255, 267*				*242, 255, 267*	
water levels	1	-1								
The extent (abundance) of the target ecosystem type (or a specific subtype) [E ab]	3	3	168			279, 306				
forest (vs. open)	2	2				279, 306				
urban green	1	1	168							

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Annex 2: Annotated list of potential MAES ecosystem condition indicators

Table A2: This table lists all indicators available and feasible to describe ecosystem characteristics relevant for flood control in the context of the EU MAES ecosystem condition assessment. All indicators are scored according to three aspects of 'usefulness':

- **rel**: relevance for flood control (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
				Age of site / community							
	1	2	2	Forest age (% of forest in age categories)		JRC, MS?	% or y	f	?	?	?
	1	1	3	**Community age (time since last major intervention/ disturbance: felling, fire, abandonment, etc)**		?	y		?	?	?
				Biomass at the site							

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	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
	1	2	2	Biomass volume (growing stock)	SEBI 017	EEA	m3/ha	f	1990-2010	**MS**	EEA39
	1	2	2	Carbon stock		FAO-FRA	t/ha	f	1990-2015	**MS**	Global
	1	1	2	Tree height		JRC, MS?	m	f	?	?	?
	1	1	2	Tree cover density		JRC, MS?, Copernicus?	%	f	?	?	?
	1	3	3	Tree crown size (diameter)		JRC, MS?, Copernicus?	m	f	?	?	?
	1	3	3	Canopy volume (from remote sensing)		JRC, Copernicus?	m3	f	?	?	?
				Site structure							
	2	1	1	Structural heterogeneity		JRC	index	f	2006	250m	EU27
				Water availability							
	2	1	1	**Water and wetness probability index (WWPI)**		Copernicus	%		2009-	100m	EEA39
	2	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	3	Extent of forest types		forest inventories?	%	f			
	1	1	1	Density of embedded seminatural elements (hedgerows, lines of trees, etc.)		JRC	%	a	2006	1km	EU27
	1	1	1	HNV area		JRC	%	a	2000, 2006	100m	EU27
				Landscape diversity							
	2	1	1	**Landscape diversity**		ETM	index		2012	?	EU28+, TR, W. Balkan
				Management / disturbance intensity (pressures)							
				All ecosystems and land uses							
O	2	1	1	**Hemeroby**		CLC, CAPRI, AFOLU			2006	100m	EU27
O	2	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	2	1	1	Intensification / extensification	AEI12	Euro-stat	index (EUR)	an	1996, 2006	NUTS2	EU 27
O(H)	2	1	1	Share of fallow land		FSS, CAPRI	%	a	2010; 2012	5km; HSU	EU28
				Grazing intensity							
O	2	1	1	Livestock density		FSS, CAPRI	LU/ha	a	2010, 2012	5km, HSU(?)	EU28
				Forest use intensity							

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
O	1	1	2	Long term ratio of annual fellings to net annual increment	SEBI 017	EEA	%	f	1990-2010	**MS**	EEA39
O	1	1	2	**Length of the felling cycle**		EEA, MS	y		?	?	?
				Soil loss							
OH	2	2	1	Soil erosion	AEI21		t/ha/y	afn	2010	1km	EU28
H	1	1	1	Imperviousness		Copernicus	%		2006-2015	20m	EEA39
				Fire regime							
C	1	1	2	Number of fires		JRC-EFFIS	1/ha/y	f	1980-	Point data	EU+
C	1	2	2	Burnt area		JRC-EFFIS	%/y	f	1980-	250m	EU+

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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.

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Annex 4: List of abbreviations

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)
BGR	biogeographic region
CAPRI	Common Agricultural Policy Regionalised Impact
CBD	Convention of Biological Diversity
CICES	Common International Classification of Ecosystem Services
CLC	Corine land cover
Corine	Coordination of Information on the Environment
DB	database
EASIN	European Alien Species Information Network
EBCC	European Bird Census Council
EEA	European Environment Agency
EEC	European Economic Community
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	ecosystem type map
EU	European Union
Eurostat	the statistical office of the European Union
FA	availability of floral resources
FSS	farm structure surveys
GIS	geographic information system
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
HSU	homogeneous spatial units (of farmlands)
IAS	invasive alien species
IMAP	Integrated Monitoring and Assessment Programme
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
KIP INCA	Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting
LRTAP	Long Range Transfer of Air Pollution
LU	livestock units
MAES	mapping and assessment of ecosystems and their services
MS	EU Member States
NS	availability of nesting sites
NUTS	nomenclature of territorial units for statistics
OpenNESS	Operationalisation of natural capital and ecosystem services (EU FP7 project)

RL	red list
SEEA-EEA	System of Environmental Economic Accounts - Experimental Ecosystem Accounts
SVL	sparsely vegetated land
TEEB	The Economics of Ecosystems and Biodiversity
UK NEA	UK National Ecosystem Assessment
WWF	World Wildlife Fund