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Ecosystem service fact sheet on pest 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 pest regulation is defined, which characteristics of the various ecosystem types are relevant for pest 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.

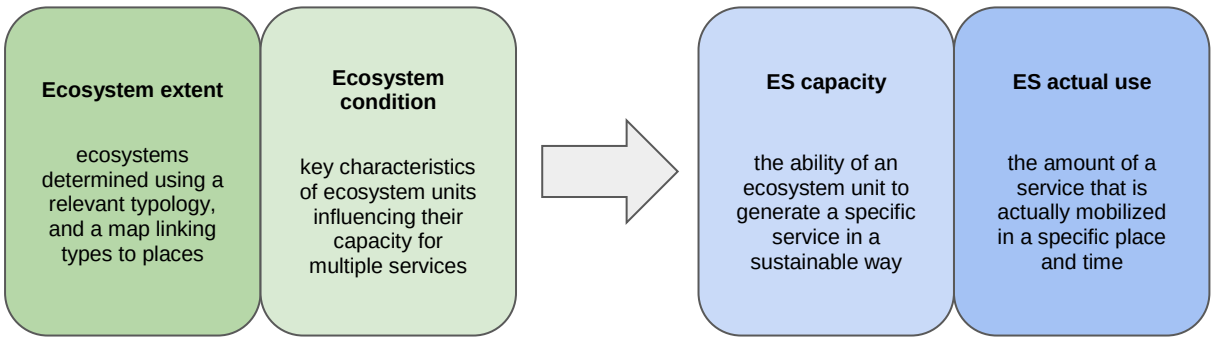

Figure 1.1: A simplified representation of the MAES conceptual framework (based on Maes et al., 2014; Burkhard et al., 2018; and MAES-INCA, 2018). The four boxes describe the main elements which need to be quantified (mapped and assessed) during the EU MAES assessment process.

2. Key messages

In this fact sheet pest regulation is regarded as suppression of pest populations in crops by natural enemies, which can be all kinds of animals, fungi and bacteria. Particularly (semi)natural ecosystems are providing this ecosystem service. There are several key condition aspects of these ecosystems relevant for pest regulation, that have been identified in this fact sheet based on a systematic review of published literature, and the availability of potential indicators for these aspects has been assessed similarly systematically (Fig. 2.1).

- The extent / abundance of small (semi)natural features (e.g. grassland stripes, hedgerows, treerows, other uncultivated land) embedded in the farmlands is a key aspect. This can be addressed using the JRC database on the *density of embedded (semi)natural elements in croplands* as an indicator.
- The presence of larger patches of (semi)natural habitat types in the proximity of farmlands is also a key aspect. Although this condition aspect is unaddressed by the available indicators as yet, it could be relatively easily deduced from the European map of ecosystem types (ETM v3.1; Weiss & Banko, 2018).
- The diversity and fragmentation of the landscape are also important factors, with several indicators available or easily implementable ('*landscape diversity*' as Shannon diversity of the ecosystem map; or the *connectivity / fragmentation of (semi-)natural landscapes* as effective mesh sizes).
- The occurrence / abundance of specific species and functional groups are relevant condition aspects, too. A possible indicator ('*rove and ground beetle richness*') is mentioned in the MAES reports as being under development. Other more general indicators for insect diversity which could be used as proxies are not available yet.

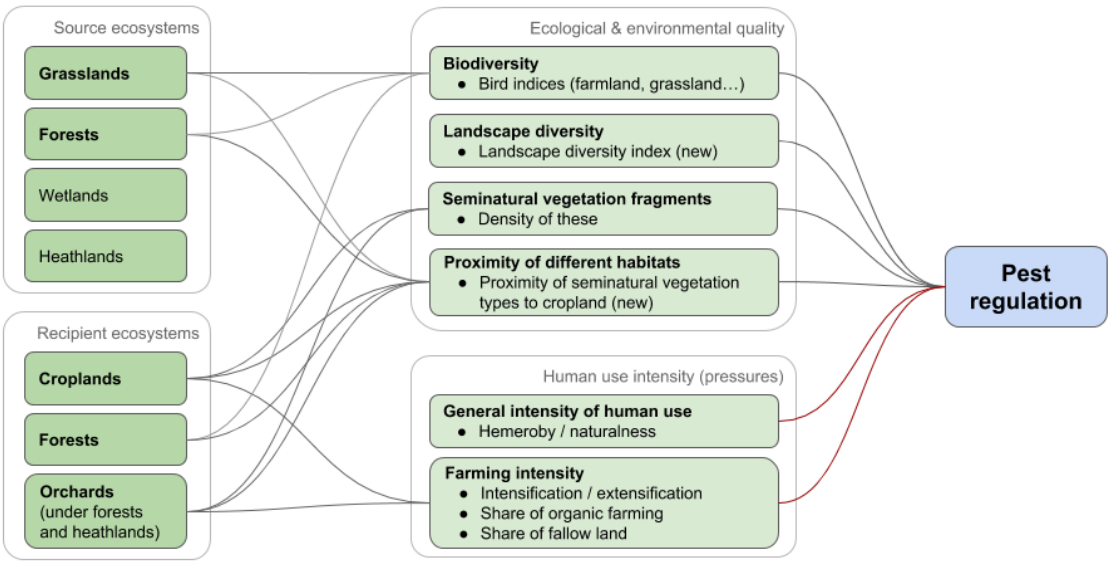

Figure 2.1: A graphical summary of this fact sheet. *Ecosystem types* (column 1) are connected to their *relevant characteristics* ('condition aspects'; column 2) and a possible set of *key indicators* (bullet points in column 2), which determine their *capacity for pest regulation* (column 3). Condition–service 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.

Several human pressures have a significant direct influence on pest regulation, and the pressures can be integrated among ecosystem condition indicators in a straightforward way.

- Management and disturbance intensity is a further important factor negatively influencing pest reduction by natural enemies. JRC & EUROSTAT offer several useful indicators here (*intensification, pesticide/fertilizer use, share of organic farming, fallow land, crop diversity*), although not all of them are available at the spatial resolution desirable for mapping. The more general *hemeroby* indicator can also be useful in adding spatial details.
- Grazing intensity also affects pest regulating arthropods, and this could be accounted for by the JRC pressure indicator '*livestock density*'.

3. Pest regulation as an ecosystem service

The suppression of pest populations in crops by natural enemies is highly relevant for ensuring food provision and therefore of immense economic value because it may reduce yield loss without the negative environmental consequences that result from pesticide use (Östmann et al. 2003). Through pest regulation natural ecosystems can contribute to the ecosystem goods produced in the neighbouring agricultural ecosystems. The first order 'beneficiaries' of pest regulation are thus all kinds of agricultural systems, typically croplands, orchards, vineyards, and urban ecosystems. Natural forests, grasslands, and wetlands can also benefit from the presence of the natural enemies in their internal biodiversity, which might increase their resilience.[1] In the strict sense, if pest regulation is considered as an ES, the 'recipient ecosystems' of this service are always human-controlled ecosystems, typically croplands (Table 3.1). The natural enemies depend on food sources and nesting sites for their development and overwintering. Mostly agricultural used fields do not provide these conditions so that (semi)natural habitats or at least embedded (semi)natural features like hedgerows, field margins, tree rows, or bushes are necessary to support the beneficial´s population growth. These ecosystem types or ecosystem features are the essential basis for the pest regulation service and thus are representing the 'source ecosystems'.

Table 3.1: The position of pest 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: 2.2.3** Pest and disease control **Class: 2.2.3.1** Pest control (including invasive species)	**IPBES**: **NCP 10** Regulation of organisms detrimental to humans **TEEB**: Biological control **MA**: Pest regulation
Definition	**Scientific**: The reduction by biological interactions of the incidence of species that prevent or reduce the output of food, material or energy from ecosystems, or their cultural importance, by consumption of biomass or competition **Simple**: Controlling pests and invasive species	**IPBES**: Regulation, by ecosystems or organisms, of pests, pathogens, predators, competitors, etc. that affect humans, plants and animals **TEEB**: Ecosystems are important for regulating pests and vector borne diseases that attack plants, animals and people. Ecosystems regulate pests and diseases through the activities of predators and parasites. Birds, bats, flies, wasps, frogs and fungi all act as natural controls.
Example for service	(Providing a habitat for native pest control agents) Reduction in pest damage to cultivated crop	
Example for benefits	(Reduction in pest damage to cultivated crop) Increased yield due to reduced pest damage	

Pest regulation by natural enemies is provided by a broad spectrum of animal species and functional groups. Beneficial organisms can be found within all groups of vertebrates, arthropods, fungi and bacteria. But most of the scientific papers dealing with pest regulation and all papers this fact sheet is based on refer to arthropod species. In particular, they refer to the beneficial contributions of insects and spiders acting as predators or parasitoids are reported in the next chapter.

Natural pest control in the CICES classification is restricted to the control of pest species that harm, destroy or diminish ecosystem goods (food, materials or energy) and/or the cultural heritage of nature. Pathogens that affect humans or animals are not directly emphasized, as opposed to IPBES, which does so. Also TEEB considers diseases harmful for humans and animals. As all literature considered in this fact sheet to illustrate the ecosystem characteristics providing the supply of natural pest control is based on the research on pest reduction in farmland ecosystems the CICES definition is used here. Therefore, neither disease control, nor 'anthropogenic' pest control by introduced biological agents are included in this fact sheet.

[1] This is frequently considered as an ecosystem function (or supporting service, cf. Potschin-Young et al., 2017; Hein, 2018) which should not be taken into account in ecosystem assessments / accounting.

4. Ecosystem characteristics influencing the supply of pest regulation

The most important ecosystem types benefitting from pest regulation are the ones carrying agricultural crops, most typically *croplands*, but due to particularities of the European map of ecosystem types (ETM v3.1; Weiss & Banko, 2018) underlying the EU MAES assessment, *forests*, *heathlands*, and *grasslands* can also serve as recipient ecosystems. Forests in ETM v3.1 include *fruit trees*, heathlands include *shrub plantations* and *vineyards*; while grasslands can include *permanent* fields of herbaceous *crops*, all of which can have pest issues, and thus benefit from pest control as a service. Furthermore, *urban* ecosystems (urban trees, parks, home gardens), and seminatural (='real') *forests* can also be the recipients of a pest regulation service. The 'natural system' supplying the service can be any (semi)natural ecosystem type, or just the subgrid (semi)natural elements nested into main human transformed ecosystem types (e.g. hedgerows or grassland strips within *cropland* or *urban* ecosystems).

Table 4.1 provides an overview on the importance of the characteristics of the main ecosystem types involved in the delivery of pest regulation. According to the scientific literature sampled in the underlying systematic review, the most relevant characteristics are the extent /abundance of any (semi)natural feature in the ecosystem supplying pest regulation, the proximity of (semi)natural ecosystem types to croplands, the landscape diversity, the intensity of farmland management, and the local biodiversity (occurrence or abundance of parasitoids and predators).

Table 4.1: Results of the systematic review: ecosystem characteristics that have been documented to influence the supply of pest regulation, 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 pest 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*
The extent (abundance) of a specific subtype (of the recipient ecosystem type)	**8**	7	0	1	crop, forest
any (semi)natural feature (hedgerows, treerows, roadsides, oldfields)	**7**	6	0	1	crop
roadsides	**1**	1	0	0	crop
The coexistence / proximity of two different ecosystem types	**5**	5	0	0	crop
any (semi)natural ecosystem type (forest, grassland, wetland)	**4**	4	0	0	crop
forest	**1**	1	0	0	crop
Management / disturbance intensity	**4**	2	2	0	crop, grass
farming intensity (fallows)	**2**	2	0	0	crop
tillage intensity	**1**	0	1	0	crop
Landscape diversity	**4**	3	0	1	crop
Occurrence / abundance of a specific species (functional) group	**3**	3	0	0	crop
parasitoids	**3**	3	0	0	crop
predators	**3**	3	0	0	crop
Biodiversity (in general)	**2**	2	0	0	crop, grass
diversity of plants	**1**	1	0	0	grass

* MAES ecosystem types: crop: cropland; grass: grassland; forest: woodland and forest

Diversity and abundance of natural enemies in an area is affected by landscape composition. A diversified agricultural landscape mosaic sustains a broader diversity of natural enemies. Therefore, biological control efficacy is higher in fields located in more complex landscapes (Winqvist et al. 2011). But according to their limited mobility beneficial arthropods are only able to reduce pest organisms in farmland areas if (semi)natural habitat patches are next to crop patches. Table 4.1 includes two types of ecosystem characteristics which provide this condition: (1) 'the extent (abundance) of a specific subtype (of the recipient ecosystem type, which benefits from the pest reduction)', and (2) 'the coexistence / proximity of two different ecosystem types'. In the first case

the (semi)natural patches are large enough to be recognized on the ecosystem map and in the second case they are very small (semi)natural patches and are considered to be part of the surrounding cropland. Therefore proportion of **(semi)natural habitats** and **existence of (semi)natural habitats in the proximity of farmlands** are informative parameters for biological control (Rusch et al. 2012). **Embedded (semi)natural features,** like hedgerows, field margins, roadsides, treerows and other uncultivated habitats, are important shelter zones for beneficial predators supporting their population growth (Legrand et al. 2011). Herbaceous non-crop habitats and wooded habitats provide a broad spectrum of natural enemies, enhanced natural enemy activity and the exchange of natural enemies between cropland and non-cropland habitats (Bianchi et al. 2006). For ground beetles the landscape cover of (semi)natural habitats was shown to be positively correlated with their functional diversity. But loss of natural habitats may also augment consumer-prey interactions depending on the degree of specialization of functionally dominant natural enemies, like generalist predators (Rand & Tscharntke 2007). Generalist predators in arable fields responded positively to increasing proportions of different types of non-crop areas in the surrounding landscapes to arable fields like woody areas (comprising forests, copses, hedges, shrub land), fallows and the length of road-side strips (Drapela et al. 2008). The length of strips of grassy road-sides directly influences activity density of generalist predators in arable fields, whereas woody areas and grassy fallows have a positive influence on total number of their off-springs (Drapela et al. 2011). Semi-natural habitats, however, are not always able to deliver these services if pests are disconnected from the available pool of natural enemies, as may be the case with invasive species (e.g. Drosophila suzukii and parasitoid wasps; Haro-Barchin et al., 2018). Moreover, semi-natural elements can sometimes also be considered as potential host for pests, especially for overwintering (e.g. pollen beetles and their predators in oilseed rape, Sutter et al., 2018).

Complex patchy landscapes with a high proportion of non-crop habitats enhance natural pest control compared to simple large-scale landscapes. **Diversified landscapes** hold most potential for the conservation of biodiversity and sustaining the pest control function (Bianchi et al. 2006). Complex landscapes enhance densities of aphid specialists whereas landscape simplification leads to an increased enemy pressure on specialised aphids (Rand & Tscharntke 2007). **Landscape diversity** is a supporting factor for natural enemies at different spatial scales. **Species richness** of general predators positively responds to the proportion of woody areas at rather small scale (radii from 500 to 1250 m) and species composition depends on woody areas and fallows at radius of 500 m (Drapela et al. 2008). Naturally occurring enemies of plant-feeding insects like parasitoids have a higher parasitism rate in a structurally rich landscape and their effect were complementary to that of ground-dwelling generalist predators (Schmidt et al. 2003).

Farming calendar and the **intensity of farming** practise has great influence on the spread of ground-dwelling predators. **Integrated management** and **direct drilling with minimum disruption of the soil surface** are the best crop management systems to the predators' survival (Legrand et al. 2011). **Choice of specific varieties** within a plant species can also lead to a reduced rate of pest infestation (Mody et al. 2011). Extensively managed field margins, rich in herbs and grasses, provide potential refuge and food resources for flower-visiting, herbivorous non-pest insects and predatory arthropods (Lagerlöf & Wallin 1993). Field margins generally have greater invertebrate abundance and taxon richness than adjacent agricultural productive fields (Ramsey et al. 2007). This increased invertebrate diversity is important to provide pest regulation. Anderson and co-authors (2013) could show that conservation field margins in an intensively managed grassland increase the abundance and richness of different arthropod trophic groups.

Natural pest regulation mostly correlates with the occurrence of specific **functional groups** of animals. As far as arthropods are concerned parasitoids (e.g. parasitic wasps) and predators (e.g. beetles or spiders) are very effective in reducing pest populations, irrespective whether they are generalists or specialists.

5. Ecosystem condition indicators relevant for pest regulation

The ecosystem characteristics listed in the previous chapter (Table 4.1) are not 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, 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 Table 4.1, with the exception of the pressure (management / disturbance intensity) indicators, which will be discussed in the next chapter.

The extent or **abundance of (semi)natural habitats** / features adjacent or in proximity to farmland or orchards is important for providing shelter zones for beneficial arthropods supporting their population growth. The density of *(semi)natural elements in croplands*, addressed by a JRC dataset (García-Feced et al., 2015) is a highly relevant condition indicator for pest regulation. The *proximity of (semi)natural habitats to farmlands* can be of similar importance, however, this condition aspect seems to be unaddressed by the available indicators as yet. Potential gap-filling indicators (e.g. the distance of farmlands to the nearest seminatural habitat) can be relatively easily calculated based on ETM. Simple 'distance to forest' or 'distance to water' indicators calculated for each location may also be relevant for pollination, and these simple indicators come with the advantage that they are more easily relevant for other ES as well (e.g. recreation, pollination), just like simple **landscape diversity & fragmentation** metrics. However, care must be taken that 'source' and 'recipient' components would be appropriately distinguished during these calculations. Accordingly, ETM subtypes will need to be distinguished, and potentially further external data sources will also be needed in the case of the forests (e.g. to distinguish an orchard from a 'real' forest).

Table 5.1: Indicators available for the ecosystem characteristics relevant for pest 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
	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 low resolution
2	Red List Index of threatened species	multiple indicators (one for each ET), only available at a very low resolution
2	Living Planet Index for Mediterranean wetlands	only available for the Mediterranean Basin, at a low spatial resolution
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
2	Forest tree species (richness)	
3	Understory vegetation (richness)	still needs to be developed
3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)	still needs to be developed, fungal diversity can be directly relevant
	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)

Table 5.1 continued.

U*	Indicator name	Comments
	Biodiversity (diversity/abundance of major species groups)	
	insects	
2	Grassland Butterfly Indicator	only available at a very low resolution
3	Wild pollinators (richness, abundance, or diversity)	still needs to be developed
3	Rove and ground beetles (richness)	needs to be developed, data source unclear
	habitats	
2	Conservation status and trends of habitats of community interest	multiple indicators (one for each ET), only available at a very low resolution
2	Threatened habitat cover	multiple indicators (one for each ET), only available at a very low resolution
2	Deadwood	only available 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
	The extent (abundance) of a specific subtype (of the target ecosystem type)	
1	**Extent of ETM subtypes**	many of the EUNIS (level 2) subtypes mapped in ETM v3.1 can be seen as meaningful w.r.t pollination (e.g. orchards vs. other forest types)
1	**Density of embedded seminatural elements (hedgerows, lines of trees, etc.)**	a key determinant of pest control
1	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	
1	**Proximity to (any) natural habitat**	a key determinant of this ES, which can be relatively easily developed
2	Proximity to forests	can be relatively easily developed
2	Proximity to wetlands	can be relatively easily developed
	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)
2	Fragmentation patterns of forest landscapes	can be (re)calculated using effective mesh sizes (fragm.geom.: forests (excl. plantations?) vs non-forests)
2	Forest connectivity	can be (re)calculated using effective mesh sizes (fragm.geom.: forests (excl. plantations?) vs non-forests – redundant with the previous one...)
3	Wetland connectivity	not really relevant for this ES, the existing indicator is simple & coarse (2 classes), should be refined/ recalculated (if needed)
1	Connectivity of seminatural elements (hedgerows...)	can be redundant with the density of seminatural elements

** 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)*

Connectivity of (semi)natural elements in farmland can be alternatively used indicating appropriate habitat situation for beneficials. But redundancy in information provided by density of (semi)natural elements has to be considered. **Local biodiversity**, as far as the existence of functional groups of arthropods is concerned, is probably an important aspect of ecosystem condition with relevance for pest reduction for which there are no good data sources. The indicator '*rove and ground beetles (richness)*' is still under development, and will probably only be implemented at the MS level, so its spatial resolution would still limit the usefulness for the EU MAES assessment. Insect diversity could also be closely related with the existence of pest control insects but the indicators needs to be developed and data sources are unclear.

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 have been 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, and there are almost no relevant pressure indicators in Table 6.1, which would fall into these categories (crop diversity is e.g. distantly linked to invasions). *Habitat loss* can be of key importance for pest control, but in most cases this type of process should not be counted as (a change in) ecosystem condition. The extent of each ecosystem type belongs to the 'ecosystem extent' box in Figure 1.1, and should thus be accounted for in other parts of the MAES assessment report. This is does not mean that habitat loss would not be important. But, any 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'.

Various aspects of land use / management intensity are generally considered as a key pressures for the ecosystems and the environment. These pressures directly influence the supply of pest regulation (see Table 4.1), and thus the relevant management characteristics of these ecosystems can be considered as meaningful condition indicators. This includes quite **general land use intensity** indicators (e.g. *hemeroby*), as well as indicators targeting specific ecosystem types (e.g. croplands or grasslands). Potential **farming intensity** indicators with relevance for pest reduction are *intensification / extensification*, *pesticide use*, *crop diversity* and *crop rotation* (which still need to be developed). *Share of fallow land* and *share of organic farming* may also indicate the existence of appropriate habitats for beneficial insects. **Grazing intensity** can be estimated with *livestock density* as an indicator, which allows to estimate the share of arthropod populations and an increased natural pest regulation.

Nutrient balance data are often correlating with the number of different species and thus are of some validity for the supply of beneficial arthropods. Indicators covering a similar 'thematics' are expected to be relatively correlated which has to be considered if they are included into the EU MAES assessment. In this respect a relevant set of indicators could comprise *hemeroby*, *intensification/extensification* and the *share of fallow land*.

Table 6.1: Indicators available for pressures relevant for pest 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	
1	**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	
1	**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
1	**Share of organic farming**	only available at a very coarse spatial resolution
1	**Share of fallow land**	
2	Crop diversity	
2	Crop rotation (functional crop groups)	still needs to be developed
	Grazing intensity	
1	Livestock density	
	Forest use intensity	
2	Long term ratio of annual fellings to net annual increment	
2	Length of the felling cycle	
	Nutrient / material balances	
2	Gross nitrogen balance	
2	Nitrogen deposition	
2	Critical load exceedance for nitrogen	multiple indicators (one for each ET)
2	Gross phosphorus balance	only available at a very coarse spatial resolution
2	Acidification	
2	Chemical status of surface/ground water	

** 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)*

7. Integrating condition indicators into pest regulation capacity models

A landscape model for biological control of cereal aphids on spring sown barley fields by different natural enemies in a Swedish agricultural region with varying landscape complexity was published by Jonsson and co-authors (2014). The model predicts how changes in landscape composition affect the abundance of different natural enemies in a specific crop-pest system, how this influences aphid numbers through predation and ultimately contributes to reduced crop damage by the aphids.

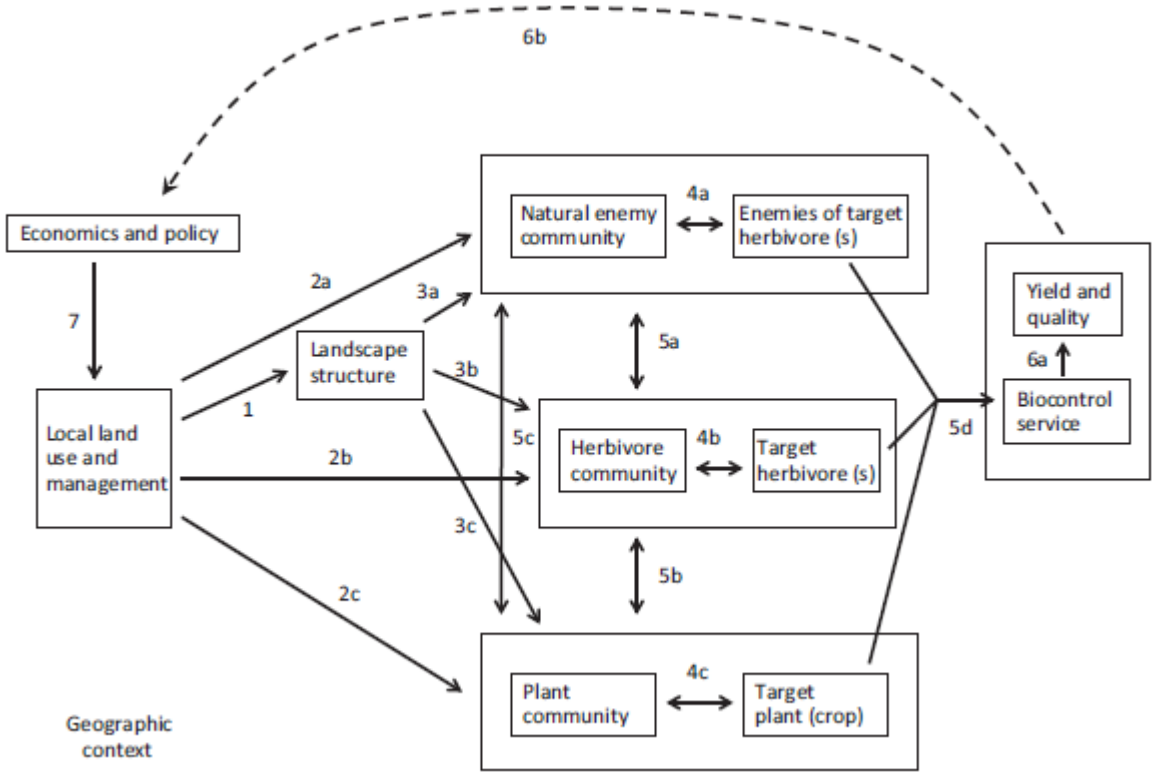

Figure 7.1: Conceptual framework for the effects of land use on biological control services (by Jonsson et al., 2014)

This cereal aphid biological control model includes only a subset of all possible interactions: (1) the influence of landscape structure on natural enemy community (3a in Fig. 7.1); (2) the influence of the natural enemy community on aphid numbers (5d); and (3) the influence of aphid predation on yield (6a).

The variables influencing natural enemy abundance used in this model are (1) proportion of **land not covered by annual crops** (= non crop land; considered within radii of 135, 500 and 3500 m of each site) and (2) proportion of **grassland within specific landscape sectors surrounding each field** (considered within a radius of 500 m). These landscape variables reflect the ecosystem characteristic types 'coexistence / proximity of (semi)natural ecosystem type' and 'landscape diversity' mentioned in Table 4.1. All landscape variables were extracted from the Swedish Integrated Administration and Control System (IACS) GIS-database, provided by the Swedish Board of Agriculture and CORINE land cover data.

The **various predator groups** considered in the model are generalist ground-dwelling predators (wolf-spiders, sheet-web spiders, ground beetles, rove beetles) and specialized foliage-dwelling predators (lady beetles, green lacewings, hoverflies). They reflect the ecosystem characteristic type 'occurrence / abundance of a specific species (functional) group' included in Table 4.1. The landscape effects on the abundance of each of various predator groups were parameterized for central Swedish conditions.

Other ecosystem condition characteristics discussed in this fact sheet like 'management / disturbance intensity', 'biodiversity (in general)' or 'the extent (abundance) of a specific subtype (of a target ecosystem type)' are not considered in this model.

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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 pest regulation, that were reanalyzed from the OpenNESS systematic review (Smith et al., 2017). The table follows the structure of Table 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 pest 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.

Characteristics type	TT	NN	urb	cro	gra	for	hea	SVL	wet	wat
Management / disturbance intensity [T mi]	4	0		50, 301, 365	172					
farming intensity (fallows)	2	2		301, 365						
tillage intensity	1	-1		50						
Biodiversity (in general) [T di]	2	2		186	172					
diversity of plants	1	1			172					
Occurrence / abundance of a specific species (functional) group [T ab]	3	3		66, 218, 232						
parasitoids	3	3		66, 218, 232						
predators	3	3		66, 218, 232						
The extent (abundance) of the target ecosystem type (or a specific subtype) [E ab]	8	7		19, 50, 66, 106, 218, 301, 365		186				
any seminatural feature (hedgerows, treerows, roadsides, oldfields)	7	6		19, 50, 66, 106, 218, 301, 365						
roadsides	1	1		365						
The co-existence / proximity of the target ET and another ET [E pr]	5	5		19, 66, 186, 301, 365						
any (semi)nautral ecosystem type (forest, grassland, wetland)	4	4		19, 66, 301, 365						
forest	1	1		186						
Landscape diversity [L di]	4	3		66, 218, 232, 301						

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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 pest regulation in the context of the EU MAES ecosystem condition assessment. All indicators are scored according to three aspects of 'usefulness':

- **rel**: relevance for pest regulation (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 3 & 4) 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 countrie s
	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	2	2	Forest tree species (richness)		AFOLU, MS?	1/area	f	~1998	100m	EU28, BY, MD
	2	3	3	Understory vegetation (richness)			1/area	f	?	?	?
	2	3	3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)			?	f	?	?	?
				birds							
	2	2	2	EU Population status and trends of bird species (%)	SEBI 003	Art12 DB	index	afn	2013, 2018	**MS**	EU
	2	2	1	*Bird indices (farmland, forest...)*	SEBI 001	EBCC	index	afn	2002-	**MS**	EU
				insects							
	1	2	2	Grassland Butterfly Indicator	SEBI 001	EEA	index	a	1990-2015	**MS**	22 MS
	1	2	3	Wild pollinators (richness, abundance, or diversity)			?	a	?	?	?
	1	2	3	Rove and ground beetles (richness)			1/area	f	?	?	?
				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	2	2	Deadwood	SEBI 018	EEA	m3/ha	f	2000-2010	**MS**	25 from EEA39
	1	1	1	Naturalness (index or typology)			index	f	?	?	?
	1	2	2	Red List Index of threatened habitats		IUCN EU RL	index	f	2017	?	?
				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
	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
				The coexistence / proximity of two different ecosystem types							
	1	1	1	**Proximity to (any) natural habitat**		ETM	km (or m)		2012-	?	EU28+, TR, W. Balkan
	1	2	1	**Proximity to forests**		ETM	km (or m)		2012	?	EU28+, TR, W. Balkan
	2	2	1	**Proximity to wetlands**		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							

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	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
	2	1	1	Fragmentation patterns of forest landscapes	SEBI 013	CLC (ETM?)	index	f	2006-2012	100m	EEA39
	2	1	1	Forest connectivity	SEBI 013	CLC (ETM?)	index	f	2006-2012	100m	EEA39
	2	3	1	Wetland connectivity		ETC/SIA	index	n	2014	Link	EU27+, TR
	1	1	1	Connectivity of seminatural elements (hedgerows...)		JRC	index	a	2006	1km	EU27
				Management / disturbance intensity (pressures)							
				All ecosystems and land uses							
O	1	1	1	**Hemeroby**		CLC, CAPRI, AFOLU			2006	100m	EU27
O	1	1	2	Human Appropriation of Net Primary Production (HANPP)		UNI Klagenfurt	kg/m2 /y of C	a	1990, 2000, 2006	1km	25 MS
				Farming intensity							
OP	1	1	1	Intensification / extensification	AEI12	Euro-stat	index (EUR)	an	1996, 2006	NUTS2	EU 27
OP	1	2	1	Mineral fertilizer consumption	~SEBI 019, AEI5	CAPRI	kg/ha/y	a	2000-2015	NUTS2	EU28
P	1	2	1	Pesticide use	AEI06	Euro-stat	kg/ha/y of act. ingred	a	2011-2014	**MS**	EU28
OP	1	1	1	Share of organic farming	SEBI 020, AEI4	FSS	%	a	2005, 2012-2016	**MS**	EU28
O(H)	1	1	1	Share of fallow land		FSS, CAPRI	%	a	2010; 2012	5km; HSU	EU28
O(I)	1	2	1	Crop diversity		FSS, CAPRI	1/area	a	2010; 2012	10km	EU28,HR : NUTS2
O	1	2	1	Crop rotation (functional crop groups)		FSS, CAPRI	1/area	a	2010	10km	EU28,HR : NUTS2
				Grazing intensity							
O	1	1	1	Livestock density		FSS, CAPRI	LU/ha	a	2010, 2012	5km, HSU(?)	EU28
				Forest use intensity							
O	2	1	2	Long term ratio of annual fellings to net annual increment	SEBI 017	EEA	%	f	1990-2010	**MS**	EEA39
O	2	1	2	**Length of the felling cycle**		EEA, MS	y		?	?	?
				Nutrient / material balances							
OP	2	1	1	Gross nitrogen balance	~SEBI 019, AEI15	CAPRI	kg/ha/y	a	1990-	1km (HSU)	EU28
P	2	1	1	Nitrogen deposition		IMAP, LRTAP	kg/ha/y	af	2005	5km	EU
P	2	1	1	*Critical load exceedance for nitrogen*	SEBI 009	EEA	% of nat. area	n	2000, 2010	50km	EU27+
OP	2	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	2	1	1	*Chemical status of surface/ground water*	SEBI 016	WISE	index	a	1992-	RBMP	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

AEI	Agri-Environmental Indicators
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
BY	Belarus
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
CSI	Core set of indicators
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
EUNIS	European Union Nature Information System
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
HR	Croatia
HSU	homogeneous spatial units (of farmlands)
IACS	Swedish Integrated Administration and Control System
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

LSI	Landscape shape index
LU	livestock units
MA	Millennium Ecosystem Assessment
MAES	mapping and assessment of ecosystems and their services
MD	Republic of Moldova
MS	EU Member States
NUTS	nomenclature of territorial units for statistics
OpenNESS	Operationalisation of natural capital and ecosystem services (EU FP7 project)
RL	red list
SEBI	Streamlining European biodiversity indicators
SEEA-EEA	System of Environmental Economic Accounts - Experimental Ecosystem Accounts
SVL	sparsely vegetated land
TEEB	The Economics of Ecosystems and Biodiversity
TR	Turkey
UK NEA	UK National Ecosystem Assessment
UNI	University
W.Balkan	West Balkan
WWF	World Wildlife Fund