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Ecosystem type fact sheet on forests

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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 forests and woodlands are defined, which forest characteristics are relevant for various ES, and what kind of indicators are available for these characteristics. The fact sheet is then concluded by a set of annexes, which contain all relevant metadata behind the whole analysis.

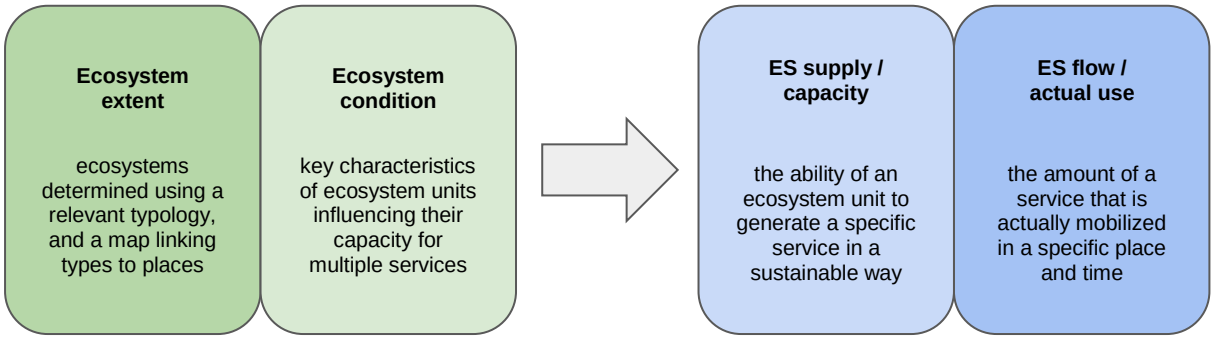

Figure 1.1: A simplified representation of the MAES conceptual framework (based on Maes et al., 2014; Burkhard et al., 2018; and MAES-INCA, 2018). The four boxes describe the main elements which need to be quantified (mapped and assessed) during the EU MAES assessment process.

2. Key messages

Forests are probably the most important ecosystem types in terms of providing ES in Europe. The multifunctionality of forests has long been recognized by European forestry sector, and has been integrated into forestry policies and management practices under the headline “forest functions”.

Assessing forest ES comes with many challenges. A key challenge is related to the starting point of the assessment: there are relevant ambiguities in the way how forests are defined in various policy documents, and these inconsistencies are inherited by the EU MAES process. The European map of ecosystem types (ETM v3.1; Weiss & Banko, 2018) maps **agricultural plantations** (fruit orchards, olive groves, etc) as forests, and offers no distinction between these (1) agricultural “forests”, (2) **intensive non-native forests** (short-cycle timber or energy plantations of non-site native trees), and “real” **semi-natural forests**. This is a clear deficiency for mapping / modelling ES, and the contradicting messages in the various MAES documents can potentially lead to errors in the MAES assessment outputs.

There are several key aspects of ecosystem condition relevant for forests, 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).

- **Biodiversity** is a key factor determining the multifunctionality of forests. Major indicators could come from the forest inventories of the Member States (tree species richness, deadwood), or regular monitoring programs (forest bird index). All of these indicators need some further work (spatial refinement).

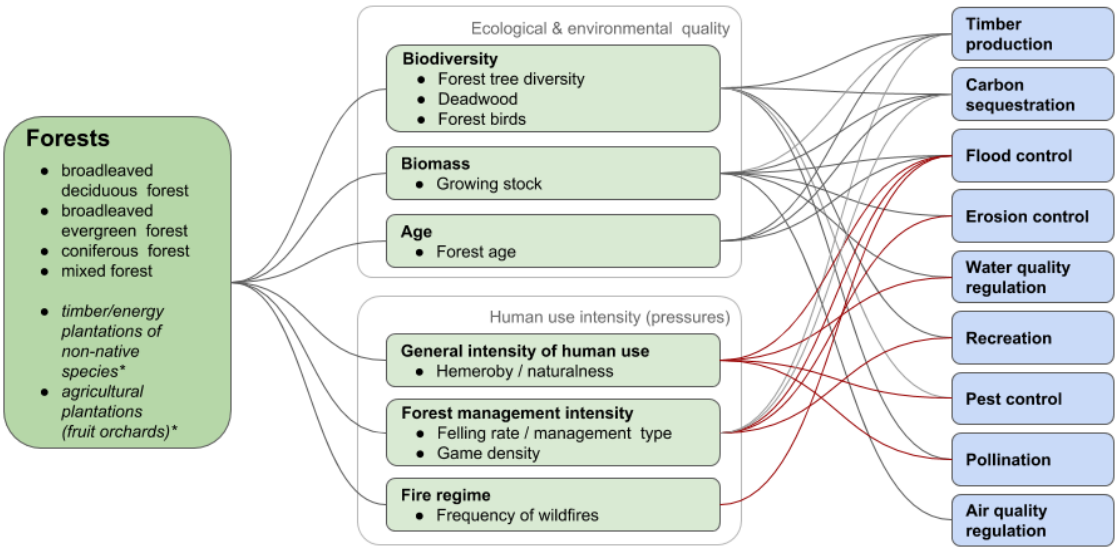

Figure 2.1: A graphical summary of this fact sheet listing *relevant aspects of forest condition*, together with their *key indicators*, and connecting them to the *ecosystem services* they influence. Condition–service connections are drawn based on a systematic review (Czúcz et al., 2018). The negative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

- The amount of forest **biomass** is a key determinant of many regulating ES, which can be best mapped /assessed with the growing stock indicator.
- The **age** of forests is also a simple but important characteristics of forests with an available indicator, which is slightly correlated with forest biomass and biodiversity.
- The type and **intensity of forest management** is a key pressure on forests, which can be characterized by the length of the felling cycle (extractable from MS forest inventories). **Game densities** is a second important pressure indicator, which could also be implemented based on MS forestry data.
- **Fires** are an increasingly important pressure on forests, which can be best characterized with an indicator on their local frequency.
- A simple indicator assigning a **hemeroby (or naturalness)** score to each forest cell based on its type (EUNIS class) could be a partial solution to the lack consistency in distinguishing intensive plantations and real forests in ETM.

3. Forests as an ecosystem type

In the 1st MAES report, the ecosystem type ***woodland and forests*** is described as "areas dominated by woody vegetation of various age or they have succession climax vegetation types on most of the area" (Maes et al., 2013, p.24). The MAES report, however, does not provide detailed definitions to the types, but links them to the categories of two major European classification systems: the European Nature Information System (EUNIS), and the CORINE land cover (CLC) classifications. The report states that the new ecosystem typology "is based on a combination of" CLC and EUNIS, with the new types "corresponding directly with (level 2 categories of) the EUNIS habitat classification". The link to the level 3 classes of CLC is established with a crosswalk table in an annex of the report (Maes et al., 2013, p.50). Unfortunately, the EUNIS classification is currently being updated, and there are some relevant differences between the old and the new EUNIS versions, which affect only a few 'marginal' subtypes of forests, and these borderline cases are absolutely relevant with respect to the delivery of several ecosystem services (pollination, pest control, water quality regulation, etc.). Furthermore, neither of the EUNIS classifications is fully compatible with the definitions of the Food and Agriculture Organization of the United Nations (FAO) which can be considered as a global reference in this topic. Table 3.1 gives an overview of the three main available forest definitions.

Table 3.1: The most important definitions for forests (EUNIS: EEA, 2012; FAO, 2012; CLC: Kosztra et al., 2017). Inconsistencies are highlighted in red. (Definitions for the revised EUNIS are not available yet.)

EUNIS 2007/2012	FAO	CLC
G. Woodland, forest and other wooded land Woodland and recently cleared or burnt land where the dominant vegetation is, or was until very recently, trees with a canopy cover > 10%. Trees are defined as woody plants, typically single-stemmed, that can reach a height of 5 m at maturity unless stunted by poor climate or soil. Includes lines of trees, coppices, regularly tilled tree nurseries, tree-crop plantations and fruit and nut tree orchards. Includes Alnus and Populus swamp woodland and riverine Salix woodland. Excludes Corylus avellana scrub and Salix and Frangula carrs. Excludes stands of climatically-limited dwarf trees (krummholz) < 3m high, such as occur at the arctic or alpine tree limit. Excludes parkland and dehesa with canopy less than 10%, which are listed under sparsely wooded grasslands (E7).	**Forest**: Land spanning >0.5 ha with trees higher than 5 m and a canopy cover >10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Forest is determined both by the presence of trees and the absence of other predominant land uses. (...) Includes: areas with young trees that (...) are expected to reach a canopy cover of at least 10% and tree height of 5 m or more. areas that are temporarily unstocked due to (...) forest management (clearcuts ...) or natural disasters, and which are expected to be regenerated within 5 years. (...) forest roads, firebreaks and other small open areas (...) windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 ha and width of more than 20 m. abandoned shifting cultivation land with a regeneration of trees that have, or are expected to reach, a canopy cover of at least 10% and tree height of at least 5 m. areas with mangroves in tidal zones (...). rubberwood, cork oak and Christmas tree plantations. areas with bamboo and palms provided that land use, height and canopy cover criteria are met. Excludes tree stands in agricultural production systems, such as fruit tree plantations, oil palm plantations, olive orchards and agroforestry systems when crops are grown under tree cover. (...)	**3.1 Forest** Vegetation formation composed principally of trees, including shrub and bush understorey. The predominant classifying parameter for this class is a crown cover density of >30% or a minimum 500 subj/ha density. The minimum tree height is 5 m & minimum patch size is 25 ha. The type includes forest clearings (<25 ha), but excludes open forests (<30% canopy cover), young plantations (< 5 m height), burnt areas, clearcuts, wooded parks, fruit and nut tree orchards, olive groves.

According to the two more coherent definitions (EUNIS, FAO) the general defining criteria of a forests is that it should consist of trees higher than 5 m with a canopy cover of more than 10%. The most important difference between the two definitions is that whereas EUNIS includes woody agricultural plantations, FAO explicitly excludes them. This might converge in the future, as in the revised version of EUNIS agricultural crops (orchards, olive groves) will be moved to "croplands" (proposed name: "vegetated man-made habitats"). The FAO definition also explicitly includes areas with young trees which might momentarily fail to meet the canopy height & cover thresholds, but are expected to reach these thresholds in situ in the near future. Both FAO and EUNIS suggest that trees standing in water (swamp woodlands, mangroves) should be considered as forests if they meet

the main criteria. FAO also sets up two related 'auxiliary' categories called "***other wooded land***" (non-agricultural & non-urban land >0.5 ha with (1) a tree (>5 m) cover of 5-10%; or with (2) a combined cover of shrubs and trees >10%) and "***other land with tree cover***" (agricultural or urban lands >0.5 ha with tree cover >10%). Nevertheless, the category "*other wooded land*" primarily coincides with the EUNIS heathlands ("heathland, scrub and tundra" in both EUNIS versions). Considering that the proposed name of the newly revised EUNIS forest category is "forest and other wooded land", the correspondence between the EUNIS and FAO classes is still expected to be the source of a lot of confusion in the future.

The place of agroforestry systems is similarly confusing in the various definitions. The CLC definition includes both arable land and pastures shaded with forestry trees (<30%). EUNIS considers silvopastoral systems as sparsely wooded *grasslands* (E7/R7), but arable agroforestry systems are not considered as a 'standalone' habitat type, just as a mosaic (X06 Crops shaded by trees). FAO, on the other hand, considers silvopastoral systems as forests (if tree cover >10%) or as other wooded land (5-10%), but it completely excludes arable agroforestry systems.

Unfortunately the inconsistencies in the definitions also exert some effects on the practical level. In addition to the one published in the 1st MAES report, a second, more detailed MAES-CLC crosswalk was created in 2014 (Banko et al., 2014). This second, which was developed to support the production of the European map of ecosystem types (ETM), The differences, that are highlighted in Table 3.2, largely reflect the inconsistencies between the three definitions previously discussed.

Table 3.2: Forest-related categories in two published MAES-CLC crosswalks (Maes et al., 2013, p.50; and Banko et al., 2014). Inconsistencies are highlighted in red.

MAES	CLC crosswalk 2013	CLC crosswalk 2014
Woodland and forest	311 Broad-leaved forest	311 Broad-leaved forest
	312 Coniferous forest	312 Coniferous forest
	313 Mixed forest	313 Mixed forest
	324 Transitional woodland shrub	324 Transitional woodland shrub
		223 Olive groves
Heathland and shrub	322 Moors and heathland	322 Moors and heathland
	323 Sclerophyllous vegetation	323 Sclerophyllous vegetation
		333 Sparsely vegetated areas**
		221 Vineyards
		222 Fruit trees and berry plantations
Cropland	(…)	(…)
	221 Vineyards	
	222 Fruit trees and berry plantations	
	223 Olive groves	
	244 Agro-forestry areas	
Grassland	(…)	(…)
		244 Agro-forestry areas

What kind of implications do these inconsistencies have for the European MAES assessment? Most importantly, contradicting definitions can cause misunderstanding and confusion, which might lead to bad calculations. The modelling of several services (pollination, pest control, habitat provision, erosion control, water quality regulation, etc.) relies on a clear distinction between managed and (semi)natural ecosystem types. As the assessment will heavily rely on the ETM produced between 2014 and 2018, the content of these maps should be the reference point, and the technical content of its mapping categories (Weiss & Banko, 2018) should override any other definition systems for the participants of the EU MAES assessment (Table 3.3). If a pollination modeller took an ETM category (e.g. G1 Broadleaved deciduous woodland) at face value, naively assuming that it's all seminatural forest and all crops needing pollination are somewhere under croplands, then this could critically compromise the modelling outputs. So for the 2020 MAES assessment the best option is to be aware of these inconsistencies, and use the categories implemented in ETM as much as possible. Luckily

the mapping categories of ETM are constructed to be very close to the level 1 classes of EUNIS 2007, which offers further help in the interpretation. And on the long run the apparent convergence between EUNIS and the FAO definitions will hopefully resolve most of the issues in a stable and reassuring way.

Table 3.3: The most important subtypes of forests available in the European map of ecosystem types (ETM v3.1), linked to CLC classes and other datasets used during the map generation (based on Weiss & Banko, 2018). The share of each subtype is given in parentheses after the subtype names.

EUNIS level 2 subtypes (+their share)		Original CLC class	Assignment rules
G1	Broadleaved deciduous woodland (39%)	311 Broad-leaved forest*	if no other rule applies
G2	Broadleaved evergreen woodland (2.5%)	233 Olive groves	always
		311 Broad-leaved forest*	if potNatVeg = evergreen AND HANTS = evergreen (priority 1)
G3	Coniferous woodland (38%)	312 Coniferous forest**	always
G4	Mixed deciduous and coniferous woodland (13%)	313 Mixed forest***	always
G5	Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice (7%)	324 Transitional woodland shrub	always

** pixels flagged as 'broadleaf forest' in HRL Forest were considered as CLC 311, irrespective of their initial CLC code (except for pixels inside the LoCo urban, riparian & N2000, for which this rule was not applied)*
*** pixels flagged as 'coniferous forest' in HRL Forest were considered as CLC 312, irrespective of their initial CLC code (except for pixels inside the LoCo urban, riparian & N2000, for which this rule was not applied)*
**** pixels flagged as 'mixed forest' in HRL Forest were considered as CLC 313, irrespective of their initial CLC code (except for pixels inside the LoCo urban, riparian & N2000, for which this rule was not applied)*

4. Relevant characteristics of forests

Forests provide a high number of essential services to humanity. In fact, they are one of the most important ecosystem types in terms of providing ES: in the systematic review underlying this work (Czúcz et al., 2018) forests were the only ecosystem type, which has been found relevant for all of the 10 studied ES. The multifunctionality of forests has long been recognized by European forestry sector, and has been integrated into forestry policies and management practices under the headline "forest functions" (Kindler, 2016). However, not all forests contribute equally to all ecosystem services, and the ES portfolio supplied by a forest is largely determined by its characteristics. Table 4.1 provides an overview on the importance of various forest characteristics for the studied services. According to the scientific literature, the most relevant characteristics are their biodiversity, management intensity, biomass (height, crown density), their age, and the type of the forest. These attributes of the forests have been documented to influence all of the studied ES, even freshwater fishing is positively influenced by the presence of forests near the bank of the streams (Lapointe et al., 2014).

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

Characteristics type	Total	Positive	Negative	Mixed	Ecosystem services*
Biodiversity (in general)	**15**	12	1	2	timber, carbon, recr, pollin
diversity of trees	**10**	8	1	1	timber, carbon
Management / disturbance intensity	**13**	1	12	0	recr, erosion, flood, timber
cutting regime	**6**	1	5	0	timber, erosion, flood, recr
fire frequency	**2**	0	2	0	flood
Biomass at the site	**11**	10	0	1	carbon, flood, a.qual, erosion, w.qual
The extent (abundance) of forests (or a forest subtype)	**8**	8	0	0	flood, a.qual, fish, pollin, pest, w.qual
Age of site / community	**7**	6	1	0	carbon, timber, flood
since cutting	**2**	2	0	0	carbon, flood
since fire	**2**	2	0	0	carbon
Occurrence / abundance of a specific species (functional) group	**4**	4	0	0	timber, carbon, erosion
Landscape diversity	**4**	4	0	0	recr, fish
Functional traits of a major species group	**2**	1	1	0	carbon, a.qual
traits of trees (leaf size, N fixing)	**2**	1	1	0	carbon, a.qual
Site structure	**2**	0	1	1	timber, recr
Soil characteristics	**2**	1	1	0	carbon, w.qual
The co-existence / proximity of forests and water [E pr]	**1**	1	0	0	recr

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

Characteristics describing **forest biodiversity** clearly influence four of the studied ES (*timber production*: e.g. Zhang et al., 2012, Merganic et al., 2013, Collet et al., 2014; *carbon sequestration*: Jonsson & Wardle, 2010, Wardle et al., 2012; *recreation*: Horne et al., 2005, Lindemann-Matthies et al., 2010; and *pollination*: Gomez et al., 2007), and they are found to be the most important (or at least most studied) forest characteristics. *Timber production* and *carbon sequestration* are primarily determined by the diversity of trees, which is beyond doubt the most important species group in forests. However, the diversity of other organism groups (e.g. understorey plants or insects) can also influence ES provisioning capacities (Gomez et al., 2007; Wardle et al., 2012).

The type and intensity of **forest management** also influences several ES. This relationship is trivial in the case of *timber production*, but *recreation* (Holgén et al., 2000) and several regulating services

(*erosion control*: Cammeraat, 2004, Maetens et al., 2012; *flood control*: Robinson et al., 2003) are also influenced by forest management. Clear-cutting is particularly bad for *erosion* and *flood control*, but other aspects of the management (e.g. if cutting residues are left on site, Robinson et al., 2003) can also be relevant. The impact of **natural disturbances**, like fire (Aronica et al., 2002; Cosandey et al., 2005) is similar to that of clear-cutting.

The amount of forest **biomass** is in a self-evident strong relationship with *timber production* and *carbon sequestration*, but which affects a high number of other regulating services as well (*flood control*: Lana-Renault et al., 2014, Robinson et al., 2003; *air quality regulation*: Beckett et al., 2000, Powe & Willis, 2004; *erosion control*: Rey, 2003; *water quality regulation*: Christen & Dalgaard, 2013). *Air quality* regulation is primarily associated to the leaf mass of trees, whereas the other services are most intensively related to the amount of biomass at or below ground level, including litter (Rey, 2003; Christen & Dalgaard, 2013).

The mere **abundance of forests in the landscape** is also documented to influence a high number of services, including *flood control* (Robinson et al., 1991; Cosandey et al., 2005), *air quality* (Powe & Willis, 2004; Hein, 2011), *pollination* (Farwig et al., 2009), *pest control* (Mody et al., 2011), and *water quality regulation* (Vought et al., 1995). There are many ways how forests can be grouped into **subtypes**, including the EUNIS level 2 subtypes (Table 3.3) that are available through ETM v3.1. These subtypes can also be relevant for several ES, most importantly *timber production* and *carbon sequestration* (Vila et al., 2007; Hulvey et al., 2013). However, as discussed in the previous chapter, the subtypes available in ETM are clearly insufficient for several ES (especially *pollination* and *pest control*), as they amalgamate highly dissimilar ecosystems, like agricultural plantations (fruit orchards), timber/energy plantations of alien (non site-native) species, and semi-natural forests (Baral et al., 2016). Ideally at least these three categories should also be distinguished as additional subtypes during the EU MAES assessment calculations of the following years, which might need some additional sources for type data beyond ETM.

The **age of forests** can also be an important aspect of their condition, which is evidently related to *timber production* and *carbon sequestration*, but also influences *flood control* (Robinson et al., 2003). Up to a certain age forest age strongly correlates with forest biomass, but later on this relationship starts to vanish. Forest age is also correlated with forest biodiversity, and this relationship gets just more pronounced in older forests (Similä et al., 2002; Lassauce et al., 2013). These correlations may give forest age an additional importance as an “indirect driver” for further ES, and the correlation pattern may also be relevant for designing an optimal set of condition indicators (see next chapter). Age diversity can also be relevant for *timber production* (Garcia-Gonzalo et al., 2007).

The **abundance of** various **functional groups** is also relevant for forest ES. The main tree groups (broadleaved deciduous, broadleaved evergreen, coniferous) are captured by the EUNIS subtype information in ETM, but there are a few further functional groups the abundance of which can be relevant for various services. This includes for example grasses and shrubs for *erosion control* (De Baets et al., 2009), and nitrogen fixers for *carbon sequestration* (Hulvey et al., 2013). The leaf size of trees can also be relevant functional trait for *air quality regulation*, with smaller leaves being more efficient (Beckett et al., 2000).

The **diversity of the landscapes** that embeds the forests can also have an impact on ecosystem services, especially in the case of *recreation*, where this seems to be the most important characteristics (Dramstad et al., 2006; van Berkel & Verburg, 2014). An aesthetical landscape consists of a balanced mosaic of open and closed patches, ideally comprising several ecosystem types, including water (García-Llorente et al., 2012).

5. Ecosystem condition indicators for forests

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

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

Table 5.1: Indicators available for the ecosystem characteristics relevant for forests. 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 coarse spatial resolution
2	Red List Index of threatened species	multiple indicators (one for each ET), at a very coarse 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)	needs to be developed, data source unclear
	plants	
3	Plant functional types (diversity)	needs to be developed, data source unclear
2	**Forest tree species (richness)**	species themselves probably best handled as subtypes, but their diversity can be used here
3	Understory vegetation (richness)	needs to be developed, data source unclear
3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)	needs to be developed, data source unclear
	birds	
2	EU Population status and trends of bird species (%)	only available at a very coarse spatial resolution
2	**Bird indices (farmland, forest…)**	multiple indicators (one for each ET), the most accessible biodiversity indicator (probably the only one which can be refined to a spatial resolution beyond NUTS2 based on existing data)
	insects	
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 coarse spatial resolution
2	Threatened habitat cover	multiple indicators (one for each ET), at a very coarse spatial resolution
2	**Deadwood**	a conceptually important indicator, currently 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

Table 5.1 continued.

U*	Indicator name	Comments
	Functional characteristics (traits) of major species groups	
3	Plant and canopy phenology (measures according to annual cycles)	needs to be developed, data source unclear, instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators; might be redundant with other indicators
3	Greening response (remote sensing proxies)	as above
3	Defoliation	as above
3	Discolouration	as above
3	Leaf-related indicators	as above
	Age of site / community	
2	**Forest age (% of forest in age categories)**	a conceptually important indicator, needs to be developed
3	Community age (time since last major intervention/ disturbance: felling, fire, abandonment, etc)	this can be confusing in the case of forests, "forest age" is simpler
	Primary productivity (& ecosystem exchange processes)	
2	Plant productivity (NPP)	
	Biomass at the site	
1	Normalized difference vegetation index (NDVI)	instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators; a single biomass indicator can be enough
1	Leaf Area Index (LAI)	as above
2	**Biomass volume (growing stock)**	a conceptually important indicator, currently available at a very coarse spatial resolution, can be redundant with other age & biomass indicators
2	Carbon stock	as above
3	Tree height	needs to be developed, redundant with other age & biomass indicators
3	Tree cover density	as above
3	Tree crown size (diameter)	as above
3	Canopy volume (from remote sensing)	as above
	Site structure	
1	Structural heterogeneity	needs to be developed, can be redundant with other indicators
	Soil characteristics	
2	C/N ratio in soil	
1	Soil organic carbon (SOC)	sampling & database is primarily focussed at croplands
3	Soil biodiversity (DNA-based richness)	under development, not available yet
2	Soil nutrients availability (nitrogen & phosphorus)	sampling & database is primarily focussed at croplands
1	Soil thickness	new proposal for a simple indicator, to follow the degradable stock behind erosion
1	Normalized difference water index (NDWI)	instantaneous values are too variable, but (multi)annual characteristics can make useful condition indicators
	The extent (abundance) of a specific subtype (of the target ecosystem type)	
1	Extent of ETM subtypes	critically important; ETM v3.1 (EUNIS level 2) subtypes are "too coarse" for many ES (see Chapter 3)
3	Extent of forest types	ideally at least three further ("level 3") subtypes should be distinguished under each category (agri. plantations, alien sp. plantations, seminat forests); data on "forest tree species" (AFOLU) can also be used here
	The coexistence / proximity of two different ecosystem types	
2	Proximity to water	
	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)
1	Fragmentation patterns of forest landscapes	can be (re)calculated using effective mesh sizes (fragm.geom.: forests (excl. plantations?) vs non-forests)
1	Forest connectivity	as above (and also redundant with it)

** 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)*

Even if there seem to be several indicators for the **biodiversity** of forests, most of them are very coarse in space, or are still in an exploratory phase of development. There is a relatively large amount of data in the *forest inventories* of the EU MS, some of which (*tree species richness, deadwood*) could potentially be used in this context. However the tree species diversity indicator still needs to be implemented, and the spatial resolution of the deadwood (SEBI 018) indicator should also be improved to reach at least the NUTS2 level. The only further taxonomic group for which there is a chance that an EU-level relatively high resolution biodiversity index can be generated in the foreseeable future is *forest birds*. These three biodiversity indicators (tree species richness, deadwood, forest birds) seem to be relatively independent and complementary as they capture relatively different aspects of forest biodiversity (dominant plants, invertebrates and fungi, birds).

The actual amount of living **biomass** (wood), as well as the long term **productivity** have long been perceived as the most important determinants of forest "quality", probably because of the intimate relationship between these characteristics and the main traditional "function" of forests: wood production. *Standing tree biomass* is still the core of each forest inventory, which is already implemented under SEBI 017, but only at a country-level resolution, and for the EU MAES assessment a finer spatial resolution would be desirable. There are also several more general remote sensing products (*NDVI, LAI*) which can also be used for developing forest condition indicators (e.g. their (multi)annual averages). The advantage of remote sensing-based biomass indicators is that they might be able to be extended beyond forest areas, potentially providing wall-to-wall coverages in a meaningful way. As biomass is a key characteristic of forests it might be justified to use multiple indicators, provided the selected indicators are not overly correlated / redundant, which should be tested during the development process.

For some of the **forest types** their share (%) within a mapping / assessment unit can also be seen as a relevant condition indicator for the forests of that area. ETM v3.1 forest types, as we have seen are perhaps not enough: even though it is important to see if a forest is broadleaved or coniferous, but this does not say anything 'normative' about their condition (i.e. if it is good or bad). For this a further distinction between level 3 EUNIS types (or at least *agricultural plantations*, *non-native timber/energy plantations*, and *semi-natural forests*) would be important. In this case it would be possible to assigning *simple naturalness / hemeroby scores* to each subtype which could serve as the basis for a relatively simple ('quick and dirty') but still robust general condition indicator. This problem could be partly solved, if these condition scores would be assigned during the process of generating the ETM map, and not after that: if the rules that assign specific habitat types to each grid cell could also assign a naturalness score to each forest cell, then even the various cases that lead to the same EUNIS class could have different naturalness scores (see Table 3.3). A great advantage of this simple approach is that the resulting general *naturalness / hemeroby indicator* could be extended seamlessly to all terrestrial ecosystem types in a transparent and robust way.

The **age of forests** is also an important aspect of their condition, which could probably be extracted relatively reliably from *forest inventory* databases. The exact details of a feasible and informative indicator (e.g. average / dominant *forest tree age*) should however still be elaborated (at a NUTS2 or finer resolution). Correlations between forest age and *(standing) tree biomass* might render one of these indicators redundant, which should also be considered during the implementation of the forest condition indicators.

There are several **biophysical / physiological properties** of forests, including plant traits and soil characteristics, which could make meaningful ecosystem condition indicators. There are several sophisticated data products based on a combination of remote sensing and modelling techniques (e.g. *canopy phenology*, *NPP*, or soil *C/N ratio*), that can be more or less readily used as forest condition indicators. The *presence of shrubs*, if this can be extracted from forest inventory datasets, can also be a relevant functional characteristics of forests.

The **diversity of the broader landscape** can also be relatively easily characterized with a relevant new indicator consisting of a *landscape diversity metric* computed on ETM (e.g. Shannon diversity with a moving window). The *connectivity / fragmentation of forests* can also be relatively easily quantified relying on ETM (the exclusion of agricultural and non-native plantations should be considered). The 'old' SEBI 013 connectivity / fragmentation maps (relying on CLC) should ideally be recalculated using one of the available robust methods (Estreguil et al., 2014; Jaeger et al., 2011). One should be enough, as most of the available indicators are expected to be highly correlated. The method should be chosen consistently with other connectivity / fragmentation maps in the EU MAES assessment.

6. Integrating pressures among forest condition indicators

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

Table 6.1: Indicators available for pressures relevant for forests. The 'usefulness' (U) 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)	
	Forest use intensity	
2	**Long term ratio of annual fellings to net annual increment**	a key indicator for forest (use) sustainability
2	**Length of the felling cycle**	a 'disturbance frequency' style simple indicator of forest use intensity (a slightly different simple indicator, which is more relevant for many ES)
3	Damage by wildlife and herbivores	needs to be developed, data source unclear, redundant with game density
3	**Game density (or ratio to sustainable levels)**	this could be a conceptually important indicator, still needs to be developed
	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	can be important for several forest types
2	Chemical status of surface/ground water	
2	Heavy metal concentrations in soil	
	Fire regime	
2	**Number of fires**	this could be a conceptually important indicator for forests
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)*

Following the logic of the systematic review, pressure indicators have been clustered according to the ecosystem types and their typical management activities/disturbance regimes instead of the HIPOC categories. From the HIPOC classes, *overexploitation* and *pollution* (='the degree of being

polluted') can be relatively easily considered as ecosystem characteristics, and thus their indicators are well represented in Table 6.1 and Annex 2. *Climate change* and *biological invasions* are, however, much more indirect pressures, with very few indicators that can be conceptualized as characteristics belonging to specific ecosystems (as e.g. fire and wildlife damage). And for *habitat loss* there are no indicators in Table 6.1 (and Annex 2), as ecosystem type transformations (deforestation or afforestation) should be handled under the ecosystem extent 'box' of the MAES framework (Figure 1.1), and not as (changes in) ecosystem condition.

The most important pressure on forests is forest management, which typically focuses at the production of wood and timber as primary goal. The intensity of this activity can be characterized by indicators, like the *long term ratio of annual fellings to net annual increment* (SEBI 017) which quantifies the sustainability of current activities, or just the *length of the felling cycle* which simply measures the frequency of this 'disturbance'. Either of these indicators can theoretically be extracted from forest inventory datasets, but they still need to be implemented, as even SEBI 017 is only published at the country level at the moment. Intensity of game management can be estimated with *game densities*, which can also be a conceptually important forest pressure indicator, with a strong impact on understorey biomass and biodiversity, and thus indirectly on several ES.

Indicators on the **frequency / magnitude of natural disturbances**, especially fires, can also be important for the condition of European forests, particularly in an era of increasing climate change. The *frequency of fires*, as well as the size (share) of *burnt areas* can be efficiently tracked with remote sensing approaches, with elaborated indicators available at JRC.

Simple indicators describing the *naturalness* (or *hemeroby*) of specific ecosystem (sub)types, as the one presented in the previous chapter, can also be considered as **general land use intensity indicators**. Data on *nutrient balance* and *acidification* can also be relevant for forests, especially as these pressure indicators are well embedded in their environmental policy domains. There are several broadly available (and partly redundant) indicators here, which should be handled in a parsimonious way, which means that a few carefully selected indicators should be enough for the EU MAES assessment (instead of including every available data stream).

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

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

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

Characteristics type	TT	NN	tim	fish	poll	pest	carb	ero	flo	w.q	rec	a.q
Management / disturbance intensity [T mi]	13	-11	263, 636					414, 445, 642	119, 278, 279		91,173,197, 466, 470	
clearcutting	4	-2	263, 636						278		197	
frequency of uncovered soil	2	-2						445, 642				
fire frequency	2	-2							119, 279			
Biodiversity (in general) [T di]	15	11	20, 54, 86, 244, 343, 400, 531, 538		8		420, 427, 447				91, 466, 470	
trees	10	7	20, 54, 86, 244, 343, 400, 531, 538				427, 447					
Occurrence / abundance of a specific species (functional) group [T ab]	4	4	20, 244				447	571				
Functional traits of a major species group [T ft]	2	0					447					235
traits of trees	2	0					447					235
Age of site / community [T ta]	7	5	54, 538				105,420, 427,486		278			
since cutting	2	2					105		278			
since fire	2	2					420, 427					
Biomass at the site [T bi]	11	10					35, 105, 420, 447	269	205, 278, 279	704		89, 235
Site structure [T st]	2	-1	636								347	
Soil characteristics [T so]	2	0					35			704		
The extent (abundance) of forests (or a subtype) [E ab]	8	8		525	58	186			279, 306	230		12, 89
The co-existence / proximity of the forests and water [E pr]	1	1									173	
Landscape diversity [L di]	4	4		525							173,175,470	

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Annex 2: Annotated list of potential MAES ecosystem condition indicators

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

- **rel**: relevance for forests (1: relevant, 2: slightly/indirectly relevant);
- **rep**: the degree to which the indicator represents the underlying condition aspect (1: good representation, e.g. indicator fully covers a major aspect → 3: poor representation);
- **ava**: availability of indicator (1: available with a good quality & spatial resolution (at least NUTS2) for most of the EU (might still need some feasible update), 2: there is something available (but needs more work), 3: still to be developed (or needs major enhancements));

Relevance (rel), representativeness (rep), and availability (ava) are highlighted with a colour scheme following that of the 2nd MAES report (Maes et al., 2014). The overall 'usefulness' of each indicator (the coloured numbers in Tables 5.1 & 6.1) is calculated as the maximum (=worst) of these three scores. The remaining columns contain the following informations / metadata:

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

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

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

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	1	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	?	?	?
	1	2	2	Forest tree species (richness)		AFOLU, MS?	1/area	f	~1998	100m	EU28, BY, MD
	1	3	3	Understory vegetation (richness)			1/area	f	?	?	?
	1	3	3	Bryophyte, moss, liverwort, lichen and fungal species richness (index)			?	f	?	?	?
				birds							
	1	2	2	EU Population status and trends of bird species (%)	SEBI 003	Art12 DB	index	afn	2013, 2018	**MS**	EU
	1	2	1	*Bird indices (farmland, forest...)*	SEBI 001	EBCC	index	afn	2002-	**MS**	EU
				insects							
	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	?	?	?
	2	2	2	Red List Index of threatened habitats		IUCN EU RL	index	f	2017	?	?
				Functional characteristics (traits) of major species groups							
	2	2	3	Plant and canopy phenology (measures according to annual cycles)			?	f			
	2	3	3	Greening response (remote sensing proxies)			?	f			
	2	2	3	Defoliation			% of trees	f			
	2	3	3	Discolouration			% of trees	f			
	2	3	3	Leaf-related indicators			?	f			
				Age of site / community							
	1	2	2	Forest age (% of forest in age categories)		JRC, MS?	% or y	f	?	?	?
	2	1	3	**Community age (time since last major intervention/ disturbance: felling, fire, abandonment, etc)**		?	y		?	?	?
				Primary productivity (& ecosystem exchange processes)							
	2	1	1	Plant productivity (NPP)		MODIS	t/ha/y	f	2000-	500m	Global
				Biomass at the site							
	1	1	1	Normalized difference vegetation index (NDVI)		Copernicus	index	f	1998-	1km	Global
	1	1	1	Leaf Area Index (LAI)		Copernicus	index	f	1998-	1km	Global

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
	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							
	1	1	1	Structural heterogeneity		JRC	index	f	2006	250m	EU27
				Soil characteristics							
	2	2	2	C/N ratio in soil		IMAP, LRTAP	%	f	2005	5km	EU
	1	1	1	Soil organic carbon (SOC)		LUCAS	% or g/kg	afn	2009, 2015	1km	EU25, EU28
	1	1	3	Soil biodiversity (DNA-based richness)		LUCAS	1/area	afn	2018		EU28
	2	2	1	Soil nutrients availability (nitrogen & phosphorus)		LUCAS	mg/kg	afn	2009, 2015	1km?	EU25, EU28
	1	1	1	**Soil thickness**		LUCAS?	cm		?	?	?
	1	1	1	**Normalized difference water index (NDWI)**		JRC	index		?	1km	Europe
				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	3	Extent of forest types		forest inventories?	%	f			
				The coexistence / proximity of two different ecosystem types							
	1	2	1	**Proximity to water**		ETM	km (or m)		2012	?	EU28+, TR, W. Balkan
				Landscape diversity							
	1	1	1	**Landscape diversity**		ETM	index		2012	?	EU28+, TR, W. Balkan
				Landscape fragmentation & connectivity							
	2	1	2	Landscape fragmentation from urban and transport infrastructure	LSI 004, CSI 054	EEA	km2	af	2012	1km	EU28+, TR, W. Balkan
	1	1	1	Fragmentation patterns of natural/seminatural landscapes	SEBI 013	CLC (ETM?)	index	fn	2006-2012	100m	EEA39
	1	1	1	Fragmentation patterns of forest landscapes	SEBI 013	CLC (ETM?)	index	f	2006-2012	100m	EEA39
	1	1	1	Forest connectivity	SEBI 013	CLC (ETM?)	index	f	2006-2012	100m	EEA39
				Management / disturbance intensity (pressures)							
				All ecosystems and land uses							
O	1	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

HI	rel	rep	ava	indicator name	indi.set	source	unit	pilot	date	s.resol	s. cover
				Forest use intensity							
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		?	?	?
O(I)	2	2	3	Damage by wildlife and herbivores			m3/y timber loss	f			
O	1	1	3	**Game density (or ratio to sustainable levels)**		MS for-estries	%		?	?	?
				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	1	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
P	1	1	2	Tropospheric ozone concentration	IND-30, CSI 005, AIR 004	EEA	ppb	f	1996-	**Points**	EU+
P	2	2	2	Heavy metal concentrations in soil		JRC D3	mg/kg/y	af	2009, 2020	1km	EU27-28
				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

AEI	agri-environmental indicator
AFOLU	agriculture, forestry and other land use
Art17 DB	Article 17 (assessments of habitats and species under the EU Habitats Directive)
Art12 DB	Article 12 (assessments of species under the EU Birds Directive)
BGR	biogeographic region
CAPRI	Common Agricultural Policy Regionalised Impact
CBD	Convention of Biological Diversity
CLC	Corine land cover
Copernicus	the Earth observation programme of the European Commission
Corine	Coordination of Information on the Environment
DB	database
DEM	digital elevation model
DNA	deoxyribonucleic acid
EBCC	European Bird Census Council
EEA	European Environment Agency
EEC	European Economic Community
ES	ecosystem service(s)
ET	ecosystem type(s)
ETC/BD	European Topic Centre on Biological Diversity
ETC/SIA	European Topic Centre for Spatial information and Analysis
ETC/ULS	European Topic Centre on Urban, Land and Soil Systems
ETM	ecosystem type map
EU	European Union
EUNIS	European Union Nature Information System
Eurostat	the statistical office of the European Union
FSS	farm structure surveys
HANPP	human appropriation of net primary production
HANTS	harmonic analysis of (NDVI) time series
HIPOC	habitat change, invasive species, pollution, overexploitation, climate change (a common list of the main drivers of environmental change)
HNV	high nature value farmlands
HRL	high resolution data layer (of Copernicus)
HSU	homogeneous spatial units (of farmlands)
IMAP	Integrated Monitoring and Assessment Programme
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
EASIN	European Alien Species Information Network
EFFIS	European Forest Fire Information System
KIP INCA	Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting
LAI	Leaf Area Index
LoCo	local component (of Copernicus)
LRTAP	Long Range Transfer of Air Pollution
LU	livestock units
LUCAS	Land Use/Cover Area frame statistical Survey
MA	Millennium Ecosystem Assessment

MAES	mapping and assessment of ecosystems and their services
MODIS	Moderate Resolution Imaging Spectroradiometer
MS	EU Member States
N2000	Natura 2000 (network of nature protection areas in the European Union)
NDVI	normalized difference vegetation index
NPP	net primary production
NUTS	nomenclature of territorial units for statistics
OpenNESS	Operationalisation of natural capital and ecosystem services (EU FP7 project)
potNatVeg	potential natural vegetation
SEBI	Streamlined European Biodiversity Indicators
SEEA-EEA	System of Environmental Economic Accounts - Experimental Ecosystem Accounts
SOC	soil organic carbon
SVL	sparsely vegetated land
TCD	tree cover density
TEEB	The Economics of Ecosystems and Biodiversity
UK NEA	UK National Ecosystem Assessment