Supplementary file 1

Supplementary online materials to the paper:

Czúcz B, Keith H, Maes J, Driver A, Jackson B, Nicholson E (2020): A common typology for ecosystem characteristics and ecosystem condition variables. One Ecosystem, 2020.

This supplement provides an overview of selected relevant classifications for ecosystem condition variables and characteristics from the ecological literature, linking them to the SEEA ECT typology:

- **Table S1:** The generic essential ecosystem characteristics (EECs) and their associated subcategories proposed by Harwell et al. (1999)
- **Table S2a:** The main types of metrics for evaluating the ecological integrity (EI) of forest ecosystems proposed by Tierney et al. (2009) based on Andreasen et al. (2001)
- **Table S2b:** The main types of metrics for evaluating the ecological integrity (EI) of wetland ecosystems proposed by Faber-Langendoen et al. (2012) based on Andreasen et al. (2001)
- **Table S3:** The Essential Biodiversity Variables (EBV) typology proposed by Pereira et al. (2013) and CBD (2013) crosswalked to SEEA ECT
- **Table S4:** The typology of natural capital attributes (NCA) proposed by Smith et al (2017)
- **Table S5:** The hierarchical structure and classification of condition indicators proposed by Maes et al. (2018)
- **Table S6:** The typology of indicators to represent the organisational state of ecosystems and landscapes proposed by Müller (2005: Table 2)
- **Table S7**: A reverse crosswalk from the SEEA ECT classes to the selected relevant classifications discussed in Tables S1-S6

Table S1: The generic essential ecosystem characteristics (EECs) and their associated subcategories proposed by Harwell et al. (1999: Table 1) crosswalked to SEEA ECT

Essential ecosystem characteristic (EEC)	**Associated subcategories**	**SEEA ECT**
1 Habitat quality	Landscape mosaic; spatial extent; landscape and community diversity; landscape connectivity and fragmentation; habitat structural diversity	C1, B2
2 Integrity of the biotic community	Biodiversity; community composition; trophic structure; economically or aesthetically important species; exotic, invasive, or noxious species; threatened or endangered species	B1
3 Ecological processes	Primary and secondary productivity; biogeochemical cycling; decomposition; energy flow; succession; spatial dynamics (dispersal, migration)	B3
4 Water quality	Biological characteristics; physical characteristics; chemical characteristics	A2
5 Hydrological system	Hydroperiod; surface and groundwater flow; water storage; water supply; channel complexity and other structural characteristics; sediment-materials transport	A1
6 Disturbance regime (changes from natural variability)	Fire frequency and intensity; flooding frequency and intensity; drought frequency and intensity; storm frequency and intensity; event frequency and intensity; disease or pest outbreaks; anthropogenic disturbances; other outside factors (e.g., sea-level rise, climate change, loss of migratory species' habitat)	B3
7 Sediment/soil quality	Biological characteristics; physical characteristics; chemical characteristics; sedimentation, soil erosion, and accumulation of soil and sediment	A1, A2

Table S2a: The main types of metrics for evaluating the ecological integrity (EI) of forest ecosystems proposed by Tierney et al. (2009; based on Andreasen et al., 2001) crosswalked to SEEA ECT

Metric type	Metric examples	SEEA ECT
1 Landscape structure	Forest patch size, anthropogenic land use	C1
2 Structure	Stand structural class; snag abundance; coarse woody debris volume	B2
3 Composition	Tree regeneration; tree condition; biotic homogenization; indicator species (invasive exotic plants, deer browse)	B1
4 Function	Tree growth and mortality rates; soil chemistry (acid stress, nitrogen saturation)	B3, A2

Table S2b: The main types of metrics for evaluating the ecological integrity (EI) of wetland ecosystems proposed by Faber-Langendoen et al. (2012; based on Andreasen et al., 2001) crosswalked to SEEA ECT

Rank Factors	Major Ecological Factors	Metric examples	SEEA ECT
Landscape context	**Landscape**	Connectivity; land use index; barriers to landward migration	C1
	Buffer	Buffer index	C1
Size	**Size**	Relative patch size; absolute patch size	--
Condition	**Vegetation**	Vegetation structure; regeneration (woody); native plant species cover; invasive exotic plant species cover; vegetation composition	B1, B2, B3
	Hydrology	Water source; hydroperiod; hydrologic connectivity	A1
	Soil	Physical patch types; soil surface condition	A1

Table S3: The Essential Biodiversity Variables (EBV) typology proposed by Pereira et al. (2013) and CBD (2013) crosswalked to SEEA ECT

EBV class	Subclass	Description (from CBD, 2013 & Kissling et al., 2018)	SEEA ECT
A Genetic composition	A1 Allelic diversity	Allelic diversity refers to the number and frequency of alleles existing in a population or sample and is the basis of other genetic diversity variables. It is important since it represents the fundamental 'library' of variation; the result of natural experimentation over billions of years. It is measured by extracting the DNA from populations of representative species at a given location and analysing it. Allelic diversity is measured at discrete positions within the genomes of target organisms. Microsatellite markers have been the main source of allelic diversity information to date. The FAO has recommended sets of markers for most domestic species. However microsatellite markers are being gradually replaced by Single Nucleotide Polymorphism (SNP). DNA-based diversity data has accumulated dramatically during the last 20 years and is now available for many species at many sites. Some species have been measured at more than one time during the recent past, allowing change detection. Single time-point data can also be used to infer past demographic trajectories, provided full genotype data are present and this represents the most immediate opportunity and may only require re-analysis of existing data. Those wild species that are directly exploited by humans (e.g. fisheries, hunted species, predators, forest trees, medicinal plants) are also well represented. Other species are more sparsely represented and need to be priorities for future data collection.	(B1)
	A2 Co-ancestry	Co-ancestry is a measure of the evolutionary history of a species or population, and is the basis of the 'phylogenetic trees' which are revolutionising taxonomy. It is built from measures of allelic diversity and supports the calculation of phylogenetic distance, which helps to prioritise the conservation of particular species or regions, where they represent a highly-unusual, often very ancient set of genes. Co-ancestry observations are available for an increasing part of the scientifically-known biodiversity	(B1)
	A3 Population genetic differentiation	This is another term for 'heterogygozity', the degree to which different populations within a species vary in their genetic composition. It is also built from fundamental observations of allelic diversity, and guides decisions on how large a fraction of species populations needs to be protected.	(B1)
	A4 Breed and variety diversity	These measures of genetic diversity predate modern DNA techniques, and are based on traditional knowledge and phenotypic expression. They represent the variation that has been developed by human selection within domesticated species. It is important for cultural and economic reasons. There are large datasets covering many breeds, land races and populations of domesticated animals and plants.	(B1)
B Species populations	B1 Species distribution	The presence or absence of a species at a given location and time is perhaps the most widely collected piece of biodiversity information. It is derived from field observations and from 'collections' data in museums and herbaria. There are hundreds of millions of such observations in digital form, covering all species and parts of the world, in repositories such as the Global Biodiversity Information Facility. The primary observations are used to construct distribution maps, using various interpolation techniques, and these form the basis of 'species richness' indicators and of most systematic conservation planning and studies of how diversity is likely to change in the future, in response to habitat loss and climate change.	B1
	B2 Population abundance	The number of organisms of a given type is fundamental to the functional aspects of biodiversity, including the calculation of sustainable harvest rates. When counting the individuals is not practical, abundance can be proxied by biomass, cover or judgement in classes such as 'common' and 'rare'. Population abundance is the continuous variable of which 'extant' or 'extinct' is an information-poor subset. It is the input to indicators such as the Living Planet Index, which currently includes only several thousand species of the millions known to exist. Population data are available for many species, sometimes in unexpected forms, such as forestry survey data or fisheries stock assessments, as well as in bird counts, wildlife census, the continuous plankton survey etc.	B1
	B3 Population	The proportions of the species population in different age classes provides information	B3

	structure by age/size class	about its longevity, turnover and past and future trends – is the population growing, declining or stable? It is needed for determining harvest rates and strategies, and for assessing extinction risk. For populations where individuals are hard to age, the sex of the organism (its height, length, girth or mass) can be used as a proxy.	(B2)
C Species traits	C1 Phenology	Presence, absence, abundance or duration of seasonal activities of organisms (timing of breeding, flowering, fruiting, emergence, host infection…)	(B2)
	C2 Morphology	Dimensions (for example, volume, mass and height), shape, other physical attributes of organisms (body mass, plant height, cell volume, leaf area, wing length, colour…)	(B2)
	C3 Reproduction	Sexual or asexual production of new individual organisms ('offspring') from parents (age at maturity, number of offspring, lifetime reproductive output)	(B2)
	C4 Physiology	Chemical or physical functions promoting organism fitness and responses to environment (thermal tolerance, disease resistance, stoichiometry e.g. chlorophyll content)	(B2)
	C5 Movement	Behaviours related to the spatial mobility of organisms (natal dispersal distance, migration routes, cell sinking of phytoplankton)	(B2)
D Community composition	D1 Taxonomic diversity	This consists of a list (sometimes with relative or absolute abundances) of species observed to coexist at a time and place, and inferred to form a community. It is the finest-scale representation of the combined species distribution data referred to above, if the latter was known to be complete, and if it were recorded with enough geographical and temporal precision – neither of which conditions are generally true. This is a fundamental measure of 'ecosystem diversity'. The information is widely collected, in the form of vegetation surveys, marine community surveys, mammal or bird assemblages, etc., but is currently poorly shared in interoperable databases.	B1
	D2 Species interactions	Species form ecosystems by interacting with one another. These interactions can take a finite number of forms: predator, prey, competitor, symbiont, dispersal agent, pollinator, among others. This information is fundamental to the building of trophic webs and for understanding how biodiversity disturbances (such as the appearance of a new disease) propagate through ecosystems and spatially. For example, understanding pollinator-plant interactions can be essential to assess how pollination services might evolve in the future. Although the basic biology of species interactions is widely observed, few international databases of interactions currently exist.	B3
E Ecosystem structure	E1 Habitat structure	Habitat structure is the three-dimensional organisation of the ecosystem: how tall, how dense and how patchy? It is particularly important because it can be observed and mapped using remote sensing, in terms of cover in various layers – for instance the height layers on land (canopy, subcanopy, herbaceous) or depth layers in aquatic systems. Habitat structure is fundamental to productivity, intactness and suitability as a place to satisfy the life-history requirements of the species which live in it – is there place for them to capture resources, nest and survive predation?	B2
	E2 Ecosystem extent and fragmentation	The area (extent) of ecosystems of different functional composition is the most widely-used indicator of ecosystem-level biodiversity loss. It has been used to assess both changes in the state of biodiversity (e.g. how many wetlands are being lost) but also as pressure (e.g. how many species are lost because of the disappearance of their habitat). The effective area can be modified by the size, shape and distance apart of individual patches – properties which are important for management and conservation, and are measured by indicators such as the mean patch size and the boundary-to-area ratio. Many local to global scale maps of ecosystem extent exist, but with legends that are difficult to reconcile without community composition data. The mapping is often implicitly based on habitat structure.	--
	E3 Ecosystem composition by functional type	This is the basis of ecosystem classification. It can be informed by community composition (see above) intersected by species traits (see above), or can be measured directly by assessing the degree of coverage by stratum for different plant life forms. The functional composition of ecosystems controls their delivery of ecosystem services, and thus their 'health' or 'degradation'.	B1 (B3)
F Ecosystem function	F1 Net primary	The capture of solar energy by plants (largely phytoplankton in aquatic systems) and its conversion into biomass (less the respiratory losses by the plant itself) forms the energy	B3

	productivity	input which sustains all life of Earth. It is the basis of most ‘provisioning’ ecosystem services such as food, fuel and timber. Sustained changes in NPP are a sensitive measure of ecosystem degradation. NPP can be directly measured using laborious field or aquatic ecosystem techniques, or by the growing network of flux stations and static or underway marine recorders, or it can be inferred from remotely-sensed measures of ocean colour and Fraction Absorbed Photosynthetic Active Radiation, fed into models along with climate and functional composition data. Such maps are available globally, every few days, at resolutions of a few hundred meters.	
	F2 Secondary productivity	Secondary production is the growth rate of organisms that live on plants: zooplankton or fish in the sea, herbivores on land. Many ecosystem services, such as fisheries, meat or dairy products, are based on secondary production, and many culturally-important forms of biodiversity (birds, mammals etc.) depend on it. Secondary production is available from fisheries models and catch databases, and from livestock numbers and offtake statistics on land.	B3
	F3 Nutrient retention	Nutrient retention refers to the ‘leakiness’ of ecosystems with respect to particular elements. For example the degree to which primary production is converted to a flux of carbon to deep ocean waters is key to the global carbon cycle and climate change. On land, the propensity of ecosystems to leak excess nitrogen and phosphorus to freshwater systems, and from there to the coast is a both an important cause of biodiversity loss and a symptom of ecosystem stress. Large databases exist of nutrient inputs to ecosystems in the form of airborne deposition, fertilisers and waste streams, as well as databases of water quality. Their linkage to biodiversity monitoring are currently largely rudimentary.	B3
	F4 Disturbance regime	The disturbance regime consists of the frequency and intensity of disrupting factors such as fires, storms or physical disturbance. The diversity of ecosystems and the species they contain is a complex function of the disturbance regime – too much disturbance or too little disturbance both lead to loss of biodiversity. Some forms of disturbance are easily and routinely monitored using remote sensing.	B3

*based on CBD (2013) for all EBV subclasses except for EBVs B1-B6, which are based on Kissling et al. (2018).

Table S4: The typology of natural capital attributes (NCA) proposed by Smith et al (2017) crosswalked to SEEA ECT

Natural capital attributes	**Description linked to ecosystem services**	**SEEA ECT**
A. Amount of vegetation	The air, soil and water regulating services—air quality, atmospheric regulation, water flow, mass flow and water quality—are governed mainly by a group of biotic attributes related to the physical amount of vegetation within an ecosystem. These services all tend to improve as the vegetated area increases, or as the density of the above- and below-ground vegetation increases. Attributes such as community/habitat type and area, structure, stand age, successional stage, stem density and above- and below-ground biomass control the provision of these services. For the service of water supply, these attributes all tend to have a negative impact.	B2 (B3)
B. Provision of supporting habitat	For services that rely on particular animal species—pollination, pest regulation and freshwater fishing—the existence of suitable habitats to support those species is found to be important: natural or seminatural habitats surrounding crops to support pollinators and predators after the crop is harvested, and suitable aquatic habitats with the right ecological, hydrological and climatic conditions to support fish through all stages of their life cycle. Community/habitat type, area and structure are therefore often correlated with these services. It is likely that supporting habitat is equally important for the service of species-based recreation, but this does not emerge strongly in the literature reviewed. As a sub-division of this category, habitat type is also important for providing aesthetic value to humans.	(B2, C1)
C. Presence of a particular species, functional group or trait	The presence of particular species is found to be important for most services, especially species-based recreation and the provision of fish, timber and food. Specific functional groups are cited as being important for some services: these include groups of pollinators and pest predators such as bees and wasps, and also, for air quality and mass flow regulation, functional groups of plants such as large-leaved vs small-leaved trees or deep vs shallow-rooted shrubs. A range of species-specific attributes are positively correlated with service supply, including species size for fishing, species-based recreation and carbon storage; and species behaviour for pollination and pest regulation.	B1 (B3)
D. Biological and physical diversity	Biological diversity, reflected in the attributes of species and functional richness, functional diversity and (for food crops) intra-species population diversity, is often positively correlated with timber, food and fish production due to resource-use complementarity (section 3.1.1) or inter-species facilitation such as nitrogen fixation from the atmosphere by leguminous plants (section 3.1.3). Species richness is also often positively correlated with the service of pollination and (though reported to a lesser extent) pest control, as a mix of organisms with different characteristics (e.g. size, shape, flight patterns) can provide a more efficient service. Physical diversity is also often found to be significant, and this is reflected in the attributes of landscape diversity and, to a large extent, community or habitat structure, though the latter also includes other aspects of structure. More complex physical structures often provide a better service, e.g. a forest with a range of vegetation heights and root depths often provides more carbon storage; more diverse habitats provide better food and shelter for pollinating insects and pest predators; structural diversity enhances the aesthetic appeal of landscapes; and structural complexity tends to improve regulation of water flow and water quality.	B1 (B2, C1)
E. Abiotic factors	Abiotic factors interact with the biotic attributes in complex and context-dependent ways, with much variation between services. Water supply appears to be particularly highly influenced by abiotic factors, with soil, precipitation and evaporation mentioned in over 70% of the articles reviewed. Food production is also dependent on a range of abiotic factors including nutrient availability, soil and precipitation. A number of services depend on water availability for establishment and survival of vegetation. In contrast, there is much less evidence on the influence of abiotic factors on pest regulation, species-based recreation and aesthetic landscapes.	A1, A2 (B3)

Table S5: The hierarchical structure and classification of condition indicators proposed by Maes et al. (2018) crosswalked to SEEA ECT

		Ecosystem condition types	Examples for indicators*	SEEA ECT
Environmental quality				
	1	Environmental quality	Percentage of population exposed to noise; Percentage of population exposed to air pollution above the standards; Concentration of air pollutants (NO2, PM10, PM2.5, O3); Percentage of population connected to urban waste water collection and treatment plants; Percentage of built up area; Tropospheric ozone (ground level ozone) concentration; Concentration of nitrogen, sulphate, sulphur, calcium and magnesium (SEBI 009); Percentage of forest under management plan or equivalent; Nutrient and BOD concentration in surface water (SEBI 016); Water Exploitation Index; Land cover in the drained area or floodplain	A1, A2
Ecosystem attributes (biological quality)				
	Structural			
	2	Structural ecosystem attributes (general)	Fragmentation (SEBI 013 and SEBI 014); Percentage area of urban green space (or percentage of natural area within the city boundaries); Share of High Nature Value farmland in agricultural area (SEBI 020) (AEI23); Share of organic farming in utilised agricultural area (SEBI 020) (AEI4); Livestock density; Deadwood (SEBI 018); Forest area; Biomass volume (growing stock) (SEBI 017); Ecological Status	B2, C1 (B3)
	3	Structural ecosystem attributes based on species diversity and abundance	Farmland Bird Indicator (SEBI 001) (AEI2.4.1); Abundance and distribution of common forest birds (SEBI 001)	B1
	4	Structural ecosystem attributes monitored under the EU nature directives	Percentage covered by Natura 2000 (SEBI 008) or by Nationally Designated Areas (SEBI 007); Conservation status and trends of species of Community interest (SEBI 003); Conservation status and trends of habitats of Community interest (SEBI 005); EU Population status and trends of bird species of Community interest (SEBI 003)	(B1)
	5	Structural soil attributes	Soil organic carbon	A1
	Functional			
	6	Functional ecosystem attributes (general)*	Water availability (m3/ha/year); Photosynthesis (e.g. indexes: NDVI (Normalized Difference Vegetation Index), VCI Copernicus (Vegetation Condition Index), fPAR (Fraction of Photosynthetically active radiation), LAI (Leaf Area Index)); Chlorophyll fluorescence (remote sensing proxies); Carbon sequestration (Dry matter productivity Copernicus) (tonne/ha/year); Plant productivity (NPP, GPP, Dry matter productivity) (tonne/ha/year); Evapotranspiration (l/ha/day); Leaf respiration (net ecosystem–atmosphere CO2 exchange); Leaf phenology type, leaf age, leaf development (measures according to annual cycles); Plant and canopy phenology (measures according to annual cycles); Carbon dioxide exchange and carbon balance (net ecosystem–atmosphere CO2 exchange); Greening response (remote sensing proxies)	B3
	7	Functional soil attributes*	Available water capacity (index); Nutrient availability (nitrogen and phosphorus) (mg/kg)	A1, A2

*Table was created on the basis of Tables 2.2 & 5.2 in Maes et al. (2018), the examples for functional attributes were taken from Tables 4.2 & 4.3

Table S6: The typology of indicators to represent the organisational state of ecosystems and landscapes proposed by Müller (2005: Table 2) crosswalked to SEEA ECT

Orientor group		Indicator	Potential key variable(s)	Comments (from the main text of Müller, 2005)*	SEEA EEA
Ecosystem structure					
1	**Biotic structures**	Biodiversity	Number of species	While ecosystems are evolving, the number of integrated species is regularly increasing steadily (..). This development is accompanied by a rising degree of information, heterogeneity and complexity. Also, specific life forms (symbiosis) and specific types of organisms (r/k strategists, organisms with rising life spans and body masses) become predominant throughout the orienting development.	B1 (B3)
2	**Abiotic structures**	Biotope heterogeneity	Index of heterogeneity	While ecosystems are evolving (...) also the abiotic features are becoming more and more complex.	C1
Ecosystem function					
3	**Energy balance**	Exergy capture, entropy production, metabolic efficiency...	Gross or net primary production, respiration per biomass...	Exergy capture (uptake of utilisable energy) is rising during the undisturbed development, the total system throughput is growing (maximum power principle, see Odum et al., 2000) as well as the articulation of the flows (ascendancy, see Ulanowicz, 2000). Due to the high number of processors and the growing amount of biomass, the energetic demand for maintenance processes and respiration is growing as well (entropy production, see Svirezhev and Steinborn, 2001).	B2 (B3)
4	**Water balance**	Biotic water flows	Transpiration per evapotranspira tion	Throughout the undisturbed development of ecosystems and landscapes, more and more elements have to be provided with water. This means that especially the water flows through the vegetation compartments show a typical orientor behaviour. These fluxes provide another high significance because they demonstrate an important prerequisite for all cycling activities in terrestrial ecosystems. The water uptake by plants, which is regulated by the degree of transpiration.	A1 (B3)
5	**Matter balance**	Nutrient loss, storage capacity	Nitrate leaching, intrabiotic nitrogen, soil organic carbon	Imported nutrients are transferred within the biotic community with a growing partition throughout undisturbed ecosystem development. Therefore, the biological nutrient fractions are rising as well as the abiotic carbon and nutrient storages, the cycling rate is growing and the efficiencies are being improved. As a result, the loss of nutrients is reduced.	A2 (A1, B3)

* The references cited here can be found in the original source (Müller, 2005)

Table S7: A crosswalk from the SEEA ECT classes to the selected relevant classifications for ecosystem condition variables and characteristics from the ecological literature discussed in Tables S1-S6

SEEA ECT groups and classes		EEC[a]	EI[b]	EBV[c]	Smith[d]	Maes[e]	Müller[f]
A Abiotic ecosystem characteristics							
	A1 Physical state characteristics	5, 7		--	E	1, 5, 7	4 (5)
	A2 Chemical state characteristics	4, 7	(4)	--	E	1, 7	5
B Biotic ecosystem characteristics							
	B1 Compositional state characteristics	2	3	B1, B2, D1, E3 (A1-4)	C, D	3 (4)	1
	B2 Structural state characteristics	1	2	E1 (B3, C1-5)	A (B, D)	2	3
	B3 Functional state characteristics	3, 6	4	B3, D2, F1-4 (E3)	(A, C, E)	6 (2)	(1, 3, 4, 5)
C Landscape and seascape characteristics							
	C1 Landscape and seascape characteristics	1	1	--	(B, D)	2	2

a: Essential Ecosystem Characteristics based on Harwell et al. (1999); see Table S1
b: Ecosystem Integrity based on Tierney et al. (2009) & Andreasen et al. (2001); see Table S2a
c: Essential Biodiversity Variables by Pereira et al. (2013); see Table S3
d: Natural capital attributes by Smith et al. (2017); see Table S4
e: Ecosystem condition types based on Maes et al. (2018); see Table S5
f: Organisational state of ecosystems and landscapes based on Müller (2005); see Table S6

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