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Chapter 5: Accounting for Ecosystem Condition

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Disclaimer:
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5 Accounting for ecosystem condition

5.1 Introduction

5.1.1 The purpose of accounting for ecosystem condition

5.1 A central feature of ecosystem accounting is its organization of biophysical information on the condition of different ecosystem assets (EAs) within an ecosystem accounting area (EAA). The ecosystem condition account provides insight about the characteristics and quality of EAs and how they have changed. Measurement of ecosystem condition is of significant interest in supporting environmental policy and decision making that is commonly focused on protecting, maintaining and restoring ecosystem condition. Comprehensive and comparable measures of ecosystem condition are therefore of direct relevance.

5.2 ***Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics***. Quality is assessed with respect to ecosystem structure, function and composition which, in turn, underpin the ecological integrity of the ecosystem, and support its capacity to supply ecosystem services. The key ecological concepts underlying the SEEA approach to defining ecosystem condition are summarized in Annex 5.1.

5.3 Ecosystem condition accounts provide a structured approach to recording and aggregating data about the quality of an ecosystem. A primary benefit of compiling ecosystem condition accounts stems from using an approach to compiling data on different aspects of ecosystem condition that supports alignment with data on ecosystem services flows. This structured approach - based on a common understanding of the size, composition and types of EAs - offers insight into changes in EAs that is more comprehensive than that provided by individual data sets. In this respect there is a strong and necessary connection to the measurement of ecosystem extent described in Chapter 4.

5.4 Ecosystem condition accounts complement environmental monitoring systems by using data from different monitoring systems, for example concerning biodiversity, water quality and soil properties. The intention of the ecosystem condition account is therefore to build upon rather than replace existing monitoring systems. Further, as described in more detail in section 5.6, ecosystem condition accounts provide a means to mainstream a wide range of ecological data into economic and development planning processes.

5.5 Although the recording of asset condition is not a standard output within economic accounts, measurement of and assumptions regarding asset condition are inherent in accounting for assets, for example in estimating rates of deterioration in the measurement of depreciation of produced assets. Generally, it is assumed that for assets that are tradeable on markets, the condition of an asset is embodied in its current market price. Since EAs do not have a market price, explicit recording of ecosystem condition in physical terms is an important aspect of completing the accounting picture.

5.1.2 General approach to compiling ecosystem condition accounts

5.6 Ecosystem condition accounts record data on the state and functioning of EAs within an EAA using a combination of relevant variables and indicators. The selected variables and indicators reflect changes over time in the key characteristics of each EA. Ecosystem condition accounts are compiled in biophysical terms and the accounting structure provides the basis for organizing the data, aggregating across both EAs of the same ecosystem type (ET) and across

ETs within an EAA, and measuring change over time between the opening and closing points of accounting periods.

5.7 The precise structure of ecosystem condition accounts will depend on the selected characteristics, data availability, uses of the accounts and policy applications. Ecosystem condition accounts are commonly compiled by ET because each type has distinct characteristics. For example, the characteristics of forests may include tree density and age while for wetlands characteristics concerning water quality and riparian zones will be relevant. However, some characteristics may be common across a number of ET, for example species richness, and other characteristics will be relevant to a combination of ET within a landscape[1], for example the diversity among different ET.

5.8 Through the use of appropriate methodological approaches and structures, it is possible to establish overall measures for ecosystem condition for individual EA, different ET and across an EAA. A three-stage approach is used in the SEEA for the compilation of ecosystem condition accounts. Outputs at each stage are relevant for policy and decision making. Each of these accounts are described in detail in section 5.3. In summary:

- In stage 1, key characteristics are selected and data on relevant variables are collated
- In stage 2, a general reference condition is determined and for each variable a corresponding reference level is established that allows a condition indicator to be derived
- In stage 3, condition indicators are normalized to support aggregation and the derivation of ecosystem condition indexes.

5.9 It is intended that these three stages in the compilation of ecosystem condition accounts are used in an integrated way. The move from one stage to another requires a progressive building of data and the use of additional assumptions. Data from each stage will be of relevance to policy and decision making.

5.2 Key components in accounting for ecosystem condition

5.2.1 Introduction

5.10 This section introduces the key components and associated terminology that is applied in the SEEA's three-stage approach to accounting for ecosystem condition. Additional detail on the various components is provided in annexes to the chapter.

5.2.2 Ecosystem condition characteristics

5.11 ***Ecosystem characteristics*** are the system properties of the ecosystem and its major abiotic and biotic components (water, soil, topography, vegetation, biomass, habitat and species) with examples of characteristics including vegetation type, water quality and soil type. The terms ecosystem characteristics is intended to encompass all of the various perspectives taken to describe the long term 'average behaviour' of an ecosystem. Characteristics include the attributes of an ecosystem asset (incl. components, structure, processes, and functionality), recurrent interactions among ecosystem assets, as well as recurrent interactions between ecosystem assets and human society. Ecosystem characteristics may be

[1] A landscape is defined for accounting purposes as a contiguous area of tightly connected, mixed ecosystem types.

stable in nature, such as soil type or topography, or dynamic and changing as a result of both natural processes and human activity, such as water quality and species abundance.

5.12 ***Ecosystem condition characteristics*** are those ecosystem characteristics that are relevant for the assessment of ecosystem condition. Generally, the focus in assessing condition will be on dynamic and changing characteristics. Data on stable characteristics should still be collected and are included in the SEEA framing as ancillary data (see 5.16).

5.13 The SEEA ***ecosystem condition typology (ECT)*** is a hierarchical typology for organizing data on ecosystem condition characteristics. By describing a meaningful ordering and coverage of characteristics, it can be used as a template for variable and indicator selection and provide a structure for aggregation. The ECT also establishes a common language to support increased comparability among different ecosystem condition studies.

5.14 Ecosystems and their characteristics are highly complex, and hence the ECT provides a balance that meets the requirements for statistical purposes and is ecologically meaningful in terms of ecosystem structure, function and composition. Since different ETs have different characteristics, which in turn should be described by different variables and indicators, the ECT is designed to be universal, i.e. it is expected to be relevant for all major ecosystem types, while also supporting the incorporation of ecosystem-specific metrics at lower levels.

5.15 The ECT is described in Table 5.1. The typology describes a set of groups and classes with the common aim of being exhaustive (i.e. broad and inclusive enough to be able to host all variables and indicators that meet relevant selection criteria (described below)) and mutually exclusive (i.e. each variable and indicator can be assigned to a unique class). Descriptions of each ECT group and class and examples of relevant variables are provided in Annex 5.2.

Table 5.1: The SEEA Ecosystem Condition Typology (SEEA ECT)

<table>
<tr><td rowspan="7">Ecosystem condition</td><td>ECT groups</td><td>ECT classes</td></tr>
<tr><td rowspan="2">Abiotic ecosystem characteristics</td><td>1. Physical state characteristics (including soil structure, water availability)</td></tr>
<tr><td>2. Chemical state characteristics (including soil nutrient levels, water quality, air pollutant concentrations)</td></tr>
<tr><td rowspan="3">Biotic ecosystem characteristics</td><td>3. Compositional state characteristics (including species-based indicators)</td></tr>
<tr><td>4. Structural state characteristics (including vegetation, biomass, food chains)</td></tr>
<tr><td>5. Functional state characteristics (including ecosystem processes, disturbance regimes)</td></tr>
<tr><td>Landscape level characteristics</td><td>6. Landscape and seascape characteristics (including landscape diversity, connectivity, fragmentation, embedded semi-natural elements in farmland)</td></tr>
</table>

5.16 ***Ancillary data.*** There are a range of commonly measured ecosystem characteristics that do not satisfy the selection criteria (described below) and hence are not recommended for use in the SEEA condition accounts. Such characteristics do not fall within scope of the ECT, i.e. the ECT is not comprehensive for all ecosystem characteristics. Data on these characteristics may however be of particular interest from scientific or policy perspectives (e.g. as input data for ecosystem service models), and in some situations may be considered appropriate proxies for the measurement of condition. Data on relevant ecosystem characteristics which for any reason do not fit into the scope of SEEA condition accounts can be distinguished using the generic label of ancillary data. Ancillary data also include variables concerning stable environmental characteristics that are unlikely to change due to human activities, like elevation or slope, but which remain relevant in the measurement of condition. Annex 5.4 describes the most common types of ancillary data.

5.2.3 Ecosystem condition variables

5.17 ***Ecosystem condition variables*** are quantitative metrics describing characteristics of an ecosystem that may be physical, chemical, biological or landscape-level. Variables measure individual characteristics. A single characteristic can have several associated variables, which may be complementary or overlapping with each other. Variables differ from characteristics (even if the same descriptor is applied to them) as they have a clear and unambiguous definition (measurement instructions, formulae, etc.) and a well-defined scale with measurement units that indicate the quantity or quality they measure. Examples of variables are the number of bird species (dimensionless), tree coverage (%) and turbidity (nephelometric turbidity unit, NTU).

5.18 Generally, selection of variables should prioritise those that reflect a role in ecosystem processes, and hence contribute to whole-ecosystem functioning, and their risk of change (Keith et al, 2013; Mace 2019). Many species traits, for example, reflect processes in which the species is involved in interactions within the ecosystem, such as fruit-eating species that disperse seeds, nectar-eating species that pollinate, decomposer organisms, and canopy emergent species that provide habitat for epiphytes.

5.19 Selection criteria can be used to prioritise and provide guidance on the selection of variables. Variables that are superior with respect to the selection criteria, for example that are more sensitive to change, should be preferred for inclusion within an ecosystem condition account. The criteria listed in Table 5.2 provide a basis for selection. The first 10 criteria are decisive as to whether a specific variable (and/or the underlying characteristic) is eligible for inclusion in the ecosystem condition accounts. The last two criteria ensure that the set of variables represents the state of the ecosystem in a meaningful way. A more detailed discussion of selection criteria is presented in Annex 5.3.

5.20 The most appropriate breadth and detail of variables selected to characterize ecosystem condition is difficult to standardize given the range of ET and differences across countries. The ECT, together with their criteria for selection, supports adoption of a pragmatic and structured approach that can be applied in all circumstances and can encompass measurement at a range of scales. Ideally, the compilation of ecosystem condition accounts should ensure that for each ET, at least one variable is selected for each of the six ECT classes. This rule of thumb aims to ensure a minimum level of comprehensiveness in the full set of condition variables.

5.21 Altogether, condition accounts should cover as much relevant ecological information as possible, using as few variables as possible. It is not expected that the measurement of condition would require the inclusion of a vast number of characteristics and variables. From an ecosystem accounting perspective, the aim is to provide a broad indication of the change in condition rather than to fully map the functions of every EA. Based on evaluation of examples of ecosystem condition accounts, a set of around six to ten indicators for a given ET can provide sufficient information to assess the overall condition of an EA. In practice, most important is incorporation of knowledge of local ecosystems and the selection of variables and metrics should be based on existing ecological knowledge and monitoring systems, with ecologists involved in the selection process.

Table 5.2: Selection criteria for ecosystem characteristics and their metrics (variables and indicators)

Criterion	Short description
Individual criteria for characteristics, variables and indicators	
Relevance	ecosystem characteristics and their metrics should be relevant in terms of the purpose of measuring ecosystem condition
State orientation	ecosystem characteristics and their metrics should describe the state of the studied ecosystem
Framework conformity	ecosystem characteristics and their metrics should be differentiated from other components of the SEEA ecosystem accounting framework
Individual criteria for variables and indicators	
Spatial reference	ecosystem condition metrics should be linked to a specific location (mapped) or spatially referenced
Temporal reference	ecosystem condition metrics should be linked to a specific time period and be sensitive to change
Feasibility	ecosystem condition metrics should (potentially) be covered by data sources over multiple EAs of the same ET
Quantitativeness	ecosystem condition metrics should be measured at a well-defined quantitative scale that allows comparisons in space and time
Reliability	primary (measured) data should be preferred over derived data which, in turn, should be preferred over modelled data.
Normativity	ecosystem condition indicators should have a strong inherent 'normative' interpretation ('good' vs 'bad', this makes it possible to turn them into indicators with the use of appropriate reference levels)
Simplicity	ecosystem condition metrics should be as simple as possible
Ensemble criteria (for the whole set of variables and indicators)	
Comprehensiveness	all relevant characteristics of the ecosystem should be covered
Parsimony (or complementarity)	the final set of ecosystem condition metrics should be free of redundant (correlated) variables

5.22 Chapters 3 and 4 highlighted the important distinction between ET whose ecosystem processes are primarily naturally driven and those ET that are more directly influenced by human activity and management. This distinction is also important in the measurement of ecosystem condition. The ECT will apply to all ET but it is noted that there is likely more similarity in the characteristics selected for natural and semi-natural ET compared to those selected for human managed, anthropogenic ET.

5.2.4 Ecosystem condition indicators, reference levels and reference condition

5.23 ***Ecosystem condition indicators*** are rescaled versions of the ecosystem condition variables, which are transformed to a common dimensionless normative scale, with the two endpoints of the scale representing favourable ("good": 1 or 100%) and unfavourable ("bad": 0 or 0%) values. Indicators can be derived when condition variables are set against reference levels. Indicators usually have the same descriptor as the associated variable. Indicators for different variables within the same ET will have different measurement units and may be measured at different scales.

5.24 A (simple) ecosystem condition indicator should always be constructed from a single variable of an ecosystem condition account. (Composite indicators of condition that are aggregated over multiple variables should be considered as sub-indexes, see section 5.3.4). Examples of indicators include the number of forest bird species expressed as a percentage of the number bird species in a pristine forest (a 'natural' reference), or water turbidity expressed in relation to levels considered as good and harmful

5.25 The values of an ecosystem condition variable which are used in rescaling the variable to an indicator are called ***reference levels***. In most cases, two reference levels (a 'favourable' and an 'unfavourable', see below) are used for rescaling. The determination of appropriate reference levels is critical to the derivation of ecosystem condition indicators (and indexes).

5.26 The SEEA adopts a structured approach to the definition of reference levels in order to support comparison and aggregation across ET. Other approaches may also be used to interpret movements in individual condition variables for specific policy and analytical requirements.

5.27 Reference levels applied to individual variables are likely to differ for different ET. For example, using the normalized difference vegetation index (NDVI)[2] to measure the variable of biomass quantity will require different reference levels for forest, savannah and grassland ecosystems.

5.28 There are several other concepts that are superficially similar to the concept of reference levels. Target levels, for example, define desired values for planning and policy, and threshold levels are science-based estimations for values at which a significant change in ecosystem functioning occurs. These values should not be used as reference levels.

5.29 The most important expectation in setting reference levels is that they would be set in a consistent way. Consistency in approach to setting reference levels should be ensured both (i) across the different variables of an ET, and (ii) for the same variable across different ETs. A careful selection of reference levels is the only way to ensure that the indicators are compatible (and comparable), and that their aggregation is ecologically meaningful.

5.30 For ecosystem accounting, a ***reference condition*** represents a state of an ecosystem which is used for setting reference levels. The best way to ensure the consistency of reference levels for different variables describing the same ET is to start out from a reference condition.[3]

5.31 For many ecosystem types, it is considered best practice to use the natural state of those ecosystems as the reference condition. This natural reference corresponds to the condition in which the structure, composition and processes (including food chains, species populations, nutrient and hydrological cycles) are intact and thus dominated by natural ecological and evolutionary processes, incorporating self-regeneration, and involving dynamic equilibria in response to natural disturbance regimes (Gibbons et al. 2008, Palmer and Febria 2012, Mackey et al. 2015).

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[2] Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). https://gisgeography.com/ndvi-normalized-difference-vegetation-index/

[3] The term reference condition is also often used to assess the impact of human activities on ecosystems. However, many related meanings have been assigned to reference condition for different purposes related to varying levels of human disturbance, where each meaning refers to specific types of assessments. It is preferable that the range of specific meanings and methods should be described by their specific terms, for example, minimally-disturbed condition, historic condition, least-disturbed condition, best-attainable condition (Stoddard et al. 2006). These specific meanings of condition incorporate implicit differences in assumptions and methods of assessment, and hence differences in classification and interpretation in the comparison of condition indices. Hence, they should not be confused with the terms reserved for reference condition as applied in the SEEA which pertain to the assessment of ecological integrity (following Stoddard et al. 2006).

5.32 Using the natural state as the reference condition allows recording the change from the natural state to be reflected in ecosystem condition accounts. This is likely of direct interest in assessing many environmental policies and associated objectives concerning conservation.

5.33 For those ecosystems in which humans have been influencing the environment for long periods of time, a 'natural' state will no longer represent a meaningful reference for condition accounts or may be impractical to use because it results in low values of indicators that measure the current condition.[4] This is particularly evident for anthropogenic ET primarily concerning agricultural and urban areas (for example IUCN GET biomes T7, F3, M4 and MT3 - see Annex 3.2). For these ET, an alternative can be found by defining an anthropogenic reference condition. Such a reference condition should be determined in relation to stable ecological conditions.

5.34 The selection of a reference condition should be applied as consistently as possible across the different realms, biomes and ET. For SEEA purposes, it is likely that countries or regions will measure ecosystem condition using a national or regionally agreed set of reference conditions. Options for establishing natural reference conditions and a gradation of anthropogenic reference conditions are summarized in Annex 5.5.

5.35 In practice, several methods can be applied to define a reference condition (Annex 5.5). Reference conditions based on the natural state of ecosystems try to identify contemporary, historically intact, or least disturbed ecosystems. Examples of contemporary reference conditions can be found in primary forests or pristine river stretches. Historical reference conditions select a specific point in time. This may be appropriate provided the point in time has specific ecological meaning or interpretation. For example, in some countries the year 1750 is used to represent a point between pre- and post- industrialization and hence ecosystem condition at that point in time is assumed to be natural. In other cases, selection of a point in time 50 years before the present might be sufficient to establish a point in time of relative ecological stability that is relevant for detecting changes in condition. Generally, however care should be taken in using an arbitrary point in time (e.g. the opening stock in the accounting period), particularly since individual years may be subject to considerable variability and inconsistency due to ecosystem dynamics.

5.36 Globally agreed reference conditions may also be used to support global comparisons, for instance to evaluate individual country commitments towards ecosystem maintenance and restoration. Examples of the use of global reference conditions are listed in Annex 5.5. It is noted that globally agreed reference conditions may incorporate aspects concerning policy targets and hence may not fully reflect the conceptual basis for reference conditions used in the SEEA.

5.2.5 Ecosystem condition indexes

5.37 **Ecosystem condition indexes** and sub-indexes are composite indicators that are aggregated from (simple) ecosystem condition indicators. The use of compatible reference levels (e.g. through a common reference condition) underpins the aggregation process.

5.38 The nested hierarchical structure of the SEEA ecosystem condition accounts offers the possibility to perform thematic aggregation in several ways (e.g. across indicators, ECT classes, or ETs). This can lead to several types of meaningful aggregated indexes, including sub-indexes for specific ECTs and ETs (e.g. a sub-index of the structural state of forests), indexes for specific

[4] In some cases, returning to the natural reference condition may not be possible because of irreversible natural disturbances, climate change or human activities such as pollution, nutrient loads, erosion or vegetation clearing.

ETs (e.g. an ecosystem condition index (ECI) for forests), indexes for specific ECTs (e.g. an ecosystem structural state index), as well as ECI covering relevant areas across an EAA. Section 5.3.4 discusses alternatives in more detail.

5.3 Structure of Ecosystem condition accounts

5.3.1 Introduction

5.39 Accounting for ecosystem condition applies a three-stage approach as introduced in Section 5.1. The data on condition organised across the three condition accounts can be presented in the form of tables, maps and graphs. The focus in this section is on the organisation of data in tables.

5.40 The three condition accounts describing respectively condition variables, condition indicators and condition indexes are built progressively to provide a comprehensive picture of ecosystem condition across multiple ET within an EAA.

5.41 The primary spatial units are ecosystem assets (EA) and these are expected to be delineated such that they are reasonably homogeneous in terms of their main characteristics (see Chapter 3), a feature that will flow on to their condition too. Ideally, and subject to data availability, it is recommended that the condition variables are recorded for each EA to ensure the full reliability and the transparency of the ecosystem condition accounts.

5.42 Conceptually, it is also possible to compile accounting tables for an individual EA, such as a single forest, wetland or farming area. Nevertheless, the measurement objective of the SEEA is to provide information about the changes in ecosystem-related stocks and flows in relatively large and diverse areas, so there is no expectation that all individual assets should be represented in a tabular form in the accounts.

5.43 It is possible that some variables are not measured at the level an individual EA, e.g. because they are defined at coarser spatial scales (e.g. concerning characteristics in ECT 6). In such cases, the value of the variable that can be measured at the location of the EA should be assigned to the EA for the purposes of condition accounting.

5.44 The precise structure of the condition accounts will vary for different combinations of variables, indicators and ETs but all structures should incorporate the core components as described in this section. Each condition account is organized with variables, indicators or indexes in the rows and ET as columns. The accounts can also be adapted to include additional rows and/or columns to record descriptive metrics such as the percentage relative to a threshold.

5.45 The accounts shown here include entries for opening and closing condition, i.e. pertaining to observations on the state of the ecosystem at the beginning and end of an accounting period. If required, accounts can incorporate entries to show a more complete time series although in this case alternative configurations for the accounts will likely be required. Ecosystem condition accounts should also present important pieces of additional information (e.g. concerning measurement units and reference levels) that clearly document the flow of information from raw data to high level indexes.

5.46 Further, for clarity of presentation, the accounts shown here include entries only for a single ET. Extensions to accommodate multiple ET, or the compilation of separate accounts for each ET should follow the same broad structure for each ET, accepting the need to record different variables and indicators.

5.47 The design of the condition accounts for a single ET can be applied for a single EA, e.g. a single forest, or for multiple EAs of the same ET. For the SEEA, the focus will be on organising information for multiple EAs which in turn will require adoption of appropriate aggregation methods and/or use of data that provides a broader assessment of condition for a given ET.

5.3.2 Stage 1: Ecosystem condition variable account

5.48 The ecosystem condition variable account is shown in Table 5.3 where opening and closing levels are recorded for selected variables for an ET. The variables are grouped based on the SEEA ecosystem condition typology (ECT).

5.49 The initial focus on variables provides a structured system for recording data on ecosystem condition. In particular, the use of standard classes of ET allows clear connections to be drawn to measures of ecosystem extent and flows of ecosystem services that are organised using the same classes.

5.50 Particular emphasis should be placed on definition and documentation of the variables and metrics included in the account since it is common for related but different variables to be used whose differences may not be apparent in the descriptor provided in the account. The documentation should contain enough information for scientific reproducibility, and they should be unambiguously linked to the short names used in the variable and indicator accounts.

5.51 The recording of variables in this account reflects an explicitly neutral approach since each metric value is not compared to a normative baseline and there is no implied judgement of relative importance, for example interpreting a value as being high, medium or low.

5.52 Since there is no information incorporated in the account to interpret the data, the application of the data in this account should focus on monitoring and reporting change in variables over time, for example in state of environment reporting. Thus, the information will support the preparation of an overall description of the changes in ecosystem condition.

5.53 In an EAA for each ET there are usually a high number of EAs, each of which can have a different condition. The values recorded in an ecosystem condition variable account should be calculated as the area weighted arithmetic mean of EAs belonging to the particular ET within the EAA. Other statistical moments (e.g. variance, median, minimum, maximum values) can also be recorded if considered useful.

Table 5.3: Ecosystem condition variable account

ECT Class	**Variables**		**Ecosystem type**		
	Descriptor	Measurement unit	Opening level	Closing level	Change in level
Physical state	Variable 1				
	Variable 2				
Chemical state	Variable 3				
Compositional state	Variable 4				
	Variable 5				
Structural state	Variable 6				
Functional state	Variable 7				
Landscape level characteristics	Variable 8				

***<<Note to reviewers:** It is intended that, pending feedback on the generic method described here, a stylised example will be incorporated such that the three condition accounts will be populated with data.>>*

5.3.3 Stage 2 – Ecosystem condition indicator account

5.54 The ecosystem condition indicator account builds directly on the ecosystem condition variable account by introducing reference levels for each variable. The variable is rescaled (transformed) to a uniform dimensionless scale [0, 1] using reference levels.

5.55 The simplest transformation to rescale variables to indicators demands two reference levels (a 'favourable' and an 'unfavourable' reference level). The indicator is calculated by a linear transformation:

$$I = (V - Vu) / (Vf - Vu)$$

where I is the value of the indicator, V is the value of the variable, Vf is the favourable and Vu is the unfavourable reference level.

5.56 Other types of rescaling functions can also be considered, but they must be justified and clearly documented in the accounts. The indicator values can also be expressed in percentage terms (0-100%). Nevertheless, this practice can be misleading, e.g. if the original indicator was already measured in percentages, or if the range of the variable contains both positive and negative values.

5.57 The favourable reference level is in most cases higher than the non-favourable one, but not always (e.g. for pollutant concentrations). Where it is not, an increase in the variable value means a decrease in the indicator.

5.58 There might be cases when the value of the variable to rescale is out of the range of the two reference levels (e.g. above the higher reference level). In such cases, it is recommended that the values of the indicator be set at 0 (0%) or 1 (100%).

5.59 One of the reference levels can often (but not always) be replaced by a natural zero value of the variable (e.g. a zero abundance for a species group, or the lack of a specific pollutant). The other reference level (or both in some cases) would then have to be set preferentially using a method that ensures a wide consistency across the different variables (e.g. by defining a natural reference condition).

5.60 The derivation of ecosystem condition indicators by comparing the variable value recorded in the previous account to an agreed reference level allows for a direct normative use of condition information for the purpose of informing policy on the state of ecosystem assets. That is, the data in the indicator account allows for descriptions to be made concerning trends in condition relative to an agreed reference level. This allows for statements concerning whether, for a given variable, ecosystem condition can be considered, for example, high or low, where a variable value that is close to the reference level is considered indicative of high condition.

5.61 In the condition indicator account, Table 5.4, the observed values for each variable are the same as in the condition variable account. Then, for each variable, the reference levels and the rescaled indicator values are provided. As for the condition variable account, the indicators are grouped based on the ECT.

5.62 The approach to establishing reference levels in the SEEA is explained in section 5.2.4. In essence, reference levels for each variable for each ET should be aligned with the chosen reference condition.

Table 5.4: Ecosystem condition indicator account

ECT Class	Indicators	Ecosystem type					
		Variable values		Reference level values		Indicator values (rescaled)	
	Descriptor	Opening value	Closing value	Unfavourable	Favourable	Opening value	Closing value
Physical state	Indicator 1						
	Indicator 2						
Chemical state	Indicator 3						
Compositional state	Indicator 4						
	Indicator 5						
Structural state	Indicator 6						
Functional state	Indicator 7						
Landscape/seascape characteristics	Indicator 8						

5.3.4 Stage 3 - Ecosystem condition index account

5.63 The ecosystem condition index account (Table 5.5) builds directly on the condition indicator account to record the aggregation of ecosystem condition indicators within an ET and across different ET. Aggregation requires the use of harmonized reference levels, e.g. through use of a single reference condition, so that different variables and classes of characteristics can be compared.

5.64 As the aggregation is performed on indicators measured on the same unfavourable to favourable scale, aggregated indexes will have the same normative range [0, 1] as the indicators. This favours an easy interpretation and a broad range of policy applications. As indexes do not need rescaling, there is no need to set reference levels for them. Some policy applications might require setting various target or threshold levels, but setting such levels is beyond the scope of the SEEA ecosystem condition accounts.

5.65 In Table 5.4, an aggregated sub-index can be derived for each ECT class and group. If there is just a single indicator in an ECT class (or group), the sub-index will be the indicator itself. If there is more than one indicator the sub-index will be a composite measure derived from a combination of indicators that describe the same ECT class or ECT group for a given ecosystem type. Weights used during the aggregation should be documented in the accounts.

5.66 The account also contains an Ecosystem Condition Index (ECI) which can be compiled for each ET. This will require the use of a second aggregation step using the sub-indices (Table 5.5). This aggregation should be performed with equal weights (or otherwise the weighting scheme should be clearly justified and documented).

Table 5.5: Ecosystem condition index account

ECT Class	Indicators		Ecosystem type	
			Index value	
	Descriptor	Indicator weight	Opening value	Closing value
Physical state	Indicator 1			
	Indicator 2			
	Sub-index			
Chemical state	Indicator 3			
Compositional state	Indicator 4			
	Indicator 5			
	Sub-index			
Structural state	Indicator 6			
Functional state	Indicator 7			
Landscape/seascape characteristics	Indicator 8			
Ecosystem condition index				

5.67 Theoretically, it is also possible to aggregate ECI across ETs into a small number of Overall Ecosystem Condition Indexes. However, aggregation across all ET will likely result in aggregating some ETs that may be regarded as fundamentally incompatible or lacking in ecological meaning. For example, aggregation across ETs from different realms (e.g. marine and terrestrial) or with different reference conditions (natural vs. anthropogenic) is not recommended.

5.68 It is also possible to develop an aggregate index for the same indicator across multiple ET, or for a single ECT class across multiple ET. Approaches to aggregation and weighting are discussed further in Annex 5.6, including noting the potential to use simple or more complex weighting patterns that allow recognition of the differing importance of some characteristics with respect to condition.

5.69 In principle, all entries in Tables 5.3-5.5 can be calculated at the level of the individual EAs. These EA-level data (and associated maps) will provide additional information compared to the accounts themselves and can be used to address relevant questions related to the variability of condition measures across an EAA. For example, assessment can be made of the share of wetlands in a very poor condition (i.e. having an ECI<0.2).

5.70 This information also suggests an alternative approach to presenting aggregate measures of ecosystem condition by recording the area of each ET that is covered by various ranges of ecosystem condition relative to the reference condition. For example, for the ET of forests, an account could show the total area of forest split into whether it was in low, medium or high condition. A low condition might represent a score of 0-30, a medium condition from 30-70 and high condition from 70-100. Area values can be reported in absolute terms (e.g., ha) or in relative terms (as a percentage of the total surface area). Different threshold scores can be used based on different methodologies to define the number of intervals and their range.

5.71 More generally, it will be the case that comprehensive assessment of ecosystem condition will require the incorporation of data on changes in ecosystem extent. This is especially the case when considering longer term and historical changes in condition where the current ET for a specific location is different from its historical ET. Changes in ET are referred to as ecosystem conversions. This topic is discussed in Chapter 4 and further discussion on conversions in the context of measuring ecosystem condition is presented below.

5.4 Considerations in the measurement of ecosystem condition

5.4.1 Introduction

5.72 The description of the three-stage approach to accounting for ecosystem condition provides an appropriate structure for measurement. Nonetheless, there are a range of different considerations and issues that will affect measurement in practice. This section discusses these issues.

5.4.2 Variables and indicators for selected ecosystem types

5.73 Following the approach described above, the measurement of ecosystem condition requires the selection of variables covering relevant ecosystem characteristics for different ETs. The general principles and criteria for the selection of variables has been outlined in section 5.2 and associated annexes. In this section, a short summary is provided of considerations in variable selections for a number of key ecosystem types. As noted above, in practice, it is important that local ecologists and related specialists are involved in the process of variable selection, as well as in the determination of reference conditions and levels.

***<<Note to reviewers**: To support compilation, it is intended to provide materials concerning the selection of variables and indicators for a selection of ET. This material, including for this section, will be developed on the basis of initial work completed during the research phase of the SEEA EEA revision process and also using the findings from testing of the approach described in this chapter that is currently underway. In the revised SEEA EEA only a summary will be provided but more detailed compilation guidance will be developed in other supporting documents.>>*

5.4.3 The use of data on environmental pressures

5.74 The measurement of environmental pressures is often considered as an indirect approach for measuring ecosystem condition (e.g. Erhard et al., 2016, p.31). If there are little data available on state, then pressures can be considered a useful surrogate, as long as the relationship between the two is well understood and justified (Bland et al. 2018). This can be considered a compromise, since conflating pressures with state variables can compromise the credibility and salience of the resulting accounting tables. At the same time, in some cases there may be little difference between a state and a pressure indicator and, in other cases, where there is a considerable lag between evidence of a pressure and a resultant change in state, a measure of pressure may provide relevant information.

5.75 Indeed, accounting tables should not be blind to the policy issues highlighted by the most relevant pressures. In the case of most pressures (e.g. erosion, pollution, invasive species) there is an underlying variable, that reflects the degradation of the ecosystem with respect to that specific pressure. This underlying variable is an environmental stock (e.g. the thickness of soil layer, the concentration(s) of pollutants, or the abundance of invasive species) that is gradually degraded by the pressure. Typically, such stocks can meet all the selection criteria, so they can be quite appropriate for condition accounting than the connected flows (e.g. degradation / depletion rates, fluxes, flows, or other indicators of flow intensity).

5.76 Using these ‘degradable stocks’ as condition indicators comes with multiple further advantages: they can be used to formulate very clear and pertinent policy messages on ecosystem degradation (concerning a change in these environmental stocks); and the degree of policy attention highlights those degradable stocks that are perceived as the most valuable or most endangered. Identifying degradable stocks in a condition account is particularly relevant when ecosystem extent is measured using remote sensing. Remote sensing will detect a stock loss due to a change in ET, e.g. clearing vegetation, but may not detect a stock loss due to degradation e.g. loss of understory or weed invasion.

5.77 A further important type of pressure is overexploitation, which can frequently be linked to degradable stocks (e.g. timber stocks for forests or fish stocks for marine ecosystems). In this case the associated ETs can have a specific target ecosystem service (typically a provisioning service) and traditional ecosystem management aims at the maximization of that service (de Groot et al., 2010). The intensity of these management activities has been shown to exert strong influences on the supply of a broad range of services, well beyond the original target ecosystem service (Santos-Martin et al., 2019).[5]

5.78 Some pressures should probably not be used in the ecosystem condition accounts, even if underlying environmental stocks can be identified. This includes pressures (or drivers) which provide more indirect measures of change in ecosystem state (e.g. climate change, human population changes). These changes should be considered external to the studied ecosystems. Habitat loss is a measure of direct pressure with a clearly identifiable degradable stock (i.e. the area of the ecosystem or habitat type in question), which should probably be omitted from condition accounts for framework conformity reasons and it should be addressed through measures of ecosystem extent rather than ecosystem condition.[6]

5.79 Indicators of protection status (e.g. the location, area, or representativeness of protected areas) are also frequently proposed as proxy measures for condition if no other information is available (e.g. Maes et al., 2016). Protection could be thought of as a rough proxy for reduced pressures, especially for reduced overexploitation (i.e. indicating lower management intensities). However, indicators describing policy interventions performed in response to degradation processes are not considered appropriate as condition indicators. There is no inherent relationship between protection status and other indicators of ecosystem condition, for example, an ecosystem could be protected and nevertheless be in poor condition. In order to avoid confusion and double counting, the use of indicators describing policy response categories should be avoided. Among other issues, including such indicators would compromise the potential to use the accounts to assess the effects of policy responses (e.g. the effect on condition of establishing a new protected area).

5.4.4 The role of biodiversity in ecosystem condition accounts

5.80 In the SEEA, the definition of ecosystems is from the Convention on Biological Diversity article 2, where ecosystems are a "*dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*". Ecosystem condition is influenced by the ecological processes involving interactions of the biota and the physical environment. Ecosystem accounting should be conducted at the level of the ecosystem rather than at the level of the individual species. The spatial accounting units should be based on ecosystem types.

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[5] Where the main/typical management of an ecosystem type can be considered as an integral part of the studied ecosystem, then it can also be seen as an internal process of the target (socio-ecological) system. In that context such internal processes may be characterized using state variables (e.g. the intensity of the default management regime), which can then be included in the condition account (in the same manner as a natural disturbance regime). This rationale is likely to be of most relevance for anthropogenic ET, including urban areas.

[6] On the other hand, if a habitat change is internal to a specific ET (e.g. soil sealing in the case of urban ecosystems), then it may be added to the condition account (preferably with an indicator describing the underlying degradable stock; e.g. the share of impervious surfaces for soil sealing). This indicator will then be specific to the given ET.

5.81 Biodiversity is defined in the SEEA according to the Convention on Biological Diversity article 2 as *“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”.* Biodiversity is conceptualized as a hierarchy at the levels of genetic, species and ecosystem diversity (King et al. 2016). The term biodiversity is used in this broad inclusive form in the discussion papers about ecosystem condition accounting. Where only taxonomic species are considered this is referred to as species diversity.

5.82 Currently in the SEEA, biodiversity has different roles in ecosystem accounts:

- as a thematic account of an ecosystem asset, usually measured as changes in species richness or abundance (in which case, this would be referred to as species diversity accounts),
- one or more characteristics or aggregated indices of biodiversity are often encapsulated in ecosystem condition accounts, which have a range of measurements as variables,
- biodiversity metrics can provide indicators of ecosystem service flows.

<<Note to reviewers: *Beyond these introductory statements, a range of materials have been developed over the past 10 years on the connection between ecosystem accounting and accounting for biodiversity. It is now clear that the connection is more nuanced than commonly appreciated and a special technical group has been convened for the purpose of clarifying the relationships, the appropriate language and choice of terms, and pathways for moving forward. This work will include reaching a common understanding on the most appropriate indicators of biodiversity for use in ecosystem accounting, clarifying issues of scale of measurement, examining links between biodiversity and flows of ecosystem services, and proposing complementary approaches for accounting for biodiversity. Findings in all of these areas will be embodied in the next draft of the revised SEEA EEA, including in this section.>>*

5.4.5 Accounting for ecosystem conversions

5.83 Ecosystem conversions occur when part or all of an ecosystem asset changes from one ET to another between the beginning and end of an accounting period. Examples of ecosystem conversions include clearing a natural forest for use by grazing animals; converting a natural grassland to cropland; urban sprawl into agricultural land; wetland restoration through in a conservation program; creation of a new hydropower reservoir; natural encroachment following permafrost melt; or the potential future flooding of coastal areas due to sea level rise.

5.84 These examples generally have clear thresholds upon which to identify a change in ET in a given location. Other examples have less clear thresholds and hence it may be more difficult to define a distinct change in ecosystem type. For example, a change in canopy cover below a certain threshold (but not zero) could result in conversion from an ecosystem type of ‘forest’ to ‘woodland’ but this may be due to land use change that removed trees or due to the partial loss of leaves during drought which is reversible. More generally, the measurement challenge is that the types of characteristics that are used to delineate EAs are also used for measuring condition and hence precise attribution of change between changes in extent and change in condition is challenging. Discussion of ecosystem conversion should therefore, necessarily, involve a joint discussion of measures of extent and measures of condition.

5.85 Primarily, the ecosystem accounting framework records ecosystem conversions in ecosystem extent accounts. Thus, where there is a change from opening to closing stock of a particular ET, the change in area will be recorded in the extent account following the principles described in Chapter 4. In tabular form, the pattern of ecosystem conversions by ET will often be shown as net changes – i.e. additions in one ET in one location within an EAA may be offset by reductions in the same ET in other locations within an EAA. Consequently, it will likely be relevant to (i) record changes at the level of the EA (e.g. as GIS data), and (ii) present these changes in gross terms – i.e. recording both additions and reductions in area of all ET. Understanding the changes in ecosystem extent is fundamental information for monitoring ecosystem conversions.

5.86 The ecosystem condition accounts require measurement of both the opening and closing condition, i.e. before and after the ecosystem conversion. Since two different ET are involved, two different sets of characteristics, variables and indicators will be measured with different reference levels. One set will apply at the opening of the period and one set will apply at the end of the period. In a standard set of ecosystem condition accounts the aggregate ECI for each ET will be affected by the change noting the need to interpret any changes in the ECI with the associated changes in ecosystem extent.

5.87 In terms of accounting and measurement process, this recording of year to year change is internally coherent and observable. However, there will likely be concern that since many ecosystem conversions represent increases in anthropogenic ET and losses of natural ET, the overall increase in distance from a natural reference condition will not be captured in the condition accounts. Following the approaches to ecosystem extent accounts in Chapter 4, it is recommended that compilers maintain data that reflects the composition of ET that existed across an EAA at an appropriately determined natural reference condition. In addition, clear distinctions between natural and anthropogenic ET should be maintained when deriving aggregate measures of condition.

5.4.6 Relationship between ecosystem condition, ecosystem capacity and supply of ecosystem services

*<<**Note to reviewers:** The connection between ecosystem condition and the supply of ecosystem services is an important relationship in ecosystem accounting but one that is challenging to describe. It is embodied in the concept of ecosystem capacity and had direct links to the description of ecosystem degradation. At this point in the SEEA EEA revision process significant advances have been made in the description of ecosystem condition, ecosystem services and ecosystem degradation. Given these advances, a discussion on the definition of ecosystem capacity will now commence bringing together experts from ecology, ecosystem services, economics and accounting. Text concerning ecosystem capacity will be developed for inclusion in the next draft for the revised SEEA EEA. Those interested in an introduction to the topic of ecosystem capacity may reference the SEEA EEA Technical Recommendations, Section 7.3.>>*

5.5 Applications of ecosystem condition accounts

5.88 Ecosystem condition accounts in a standardized SEEA framework can be applied at regional, national and international scales for a wide range of applications. Data for different components of condition accounts, such as ecosystem variables, indicators, reference levels, reference conditions and ecosystem condition indexes, are used for different applications.

Ensuring consistency in terms, definitions and metrics between the information system provided by the ecosystem accounts and the policy documents will ensure effective application.

5.89 Condition accounts are used to synthesize information about changes over time in the state of ecosystem assets. This information can be used to inform policy and decision-making across a range of sectors that impact on or depend on ecosystems and natural resources, including land-use planning, environmental impact assessment, agricultural planning and authorization processes, and programmes for ecosystem rehabilitation or restoration. Overall measures from ecosystem condition accounts (such as an ecosystem condition index) can be used to inform strategic planning at the national level. Where accounts are compiled with spatially explicit detail, and include information on particular characteristics of ecosystem assets, the accounts can also be used to inform landscape-level planning.

5.90 The use of variables, indicators, or ancillary information to assess the capacity of ecosystems to supply ecosystem services is an important application for the purpose of informing policy on the future availability of ecosystem service flows from ecosystem assets. Following SNA conventions, information on future ecosystem service flows may be used for estimating an economic value of ecosystem assets.

5.91 Several examples demonstrate the range of applications of ecosystem condition accounts in providing information. Quantification of indicators and reference levels can be used to operationalize the definition of ecosystem degradation and restoration. Further, indicators of ecosystem condition could be combined with information on ecological thresholds (e.g. concerning points of change in ET) to assess the risk of change, or alternatively, to assess the degree of resilience within ecosystems under conditions of change.

5.92 Some cases of assessment of ecosystem condition or capacity to supply ecosystem services will depend on complex interrelationships of multiple indicators for determining threshold levels to define sustainability. The ability to connect the critical levels of ecosystem service capacity back to the ecosystem condition variables that have the highest influence on specific ecosystem services would be a valuable exercise to explore. This would allow information in the ecosystem accounts to be applied to quantifying the 'critical natural capital' described in economics (Ayers et al. 2001) or the 'planetary boundaries' concept in ecology (Rockström et al. 2009).

5.93 The development of ecosystem condition accounts has the potential to make many key policy commitments measurable, and thus more easily implementable, at the national and international level. The measurement may then, in turn, support the design and development of policy and associated targets. International policies where the information from ecosystem condition accounts can be applied include measures of land degradation to support the goal of land degradation neutrality (LDN) under the UN Convention on Combatting Desertification (UNCCD, 1994), the Sustainable Development Goals (UN 2018), and the Aichi Biodiversity Targets (CBD 2010). Further, in the UNFCCC Paris Agreement (UN 2015), the inclusion of the concept that ecosystem integrity must be promoted while accounting for national emissions reductions demonstrates significant progress in adopting a holistic approach to environmental issues. This concept is developed further in a report describing specific mitigation actions (CLARA 2018). The interconnectedness of the various characteristics used to describe ecosystem condition are required to report on targets such as LDN, the SDGs and the Aichi Targets.

5.94 A difference between scientific and policy aims in the development and use of condition indicators is that scientists aim to understand the complexity of ecosystems and encapsulate this reality, whereas policy-makers often need headline indicators of the ecosystem that can be evaluated readily with indicators representing economic, social, political and other realities. Accounting thus needs to support both the overview and the detail. Hence, individual variables, indicators and ecosystem condition indexes all have a role in applying ecosystem condition accounts in decision making.

Annex 5.1: Conceptual framing for ecosystem condition

The condition of an ecosystem asset is interpreted as the ensemble of multiple relevant ecosystem characteristics, which are measured by sets of variables and indicators that in turn are used to compile the accounts. Indicators are selected in relation to the context and purpose of assessment, and different considerations will be relevant across natural and human-modified ecosystems. Individual indicators can be aggregated to broader indices that provide a synthesis of the integrity, health or naturalness of an ecosystem asset.

Ecosystem assets are multi-functional, adaptable and resilient, but they also exhibit features that are irreversible (Mace 2019). The capacity of ecosystem assets for regeneration and reorganization should be considered a major criterion for assessing ecosystem condition, and hence the basis for selecting variables and indicators that reflect these ecological processes and functions recognising the complexities and non-linearities involved (Mace 2019).

Several long-standing integrating concepts in the history of ecological knowledge are closely related to the concept of ecosystem condition as used in ecosystem accounting. These concepts, even if they may have been designed for other related environmental purposes, provide the theoretical basis for designing aggregated condition measures. The concept of ecosystem integrity was introduced by Leopold (1944, 1949) to characterize basic requirements for the stability of biotic communities. In the following decades there were several similar, partly synonymous terms (e.g. ecosystem health, resilience, naturalness) introduced in various disciplines to assess the state of the environment (for example, Cairns 1977).

Associations among terms are described by Principe et al. (2012) and Roche and Campagne (2017), a series of examples provided in DellaSala et al (2018), and the role of ecosystem integrity in ethics and human well-being is articulated by Mackey (2007). The concepts of ensuring the integrity of all ecosystems and protection of biodiversity are incorporated in the Convention on Biological Diversity (CBD, 1992) and the Paris Agreement (UNFCCC 2015). A key aspect of these concepts is that they encompass consideration of both ecosystem conservation and the sustainable use of ecosystem services by humans.

The following interpretations and overlaps are considered relevant in the discussion of ecosystem condition for accounting purposes.

Ecosystem integrity: Ecosystem integrity is defined as the system's capacity to maintain structure and autonomous functioning using processes and elements characteristic for its ecoregion (Dorren et al., 2004). The system has the capacity for self-regeneration and maintains diversity of organisms and their interrelationships to allow evolutionary processes for the ecosystem to persist over time at the landscape level (Norton 1992). The capacity for evolutionary processes requires a redundancy reserve of latent genetic material and processes that can be used in the future. In the context of ecosystem accounting, the persistence of system 'integrity' can be used as a characteristic of ecosystem condition, but may be measured using several indicators.

Ecosystem resilience: Ecosystem resilience is the inherent ability to absorb or recover from disturbances and reorganize while undergoing state changes to maintain critical structure and functions. This is closely related to the capacity for self-regeneration that forms part of the definition of ecosystem integrity above.

Ecosystem health: 'Ecosystem health' is a common term used in environmental science and management as a way to describe the state of a system relative to a reference condition or a desired management target. Combinations of biological, physical and chemical indicators are used, and often in a manner to describe functioning as a self-organised system (Rapport, 1989; Schaeffer et al., 1988, O'Brien et al. 2016).

Naturalness / hemeroby / degree of modification: These concepts describe the distance of an ecosystem from an (undisturbed) reference condition, or the degree of anthropogenic influence on the ecosystem. In the terrestrial realm, it is often assessed through land cover and land use type (Burkhard and Maes 2017).

Red List of Ecosystems – ecosystem status and risk of collapse: The International Union for Conservation of Nature (IUCN) Red List of Ecosystems (RLE) deals with the status of ecosystems and the risk of ecosystem collapse rather than with ecosystem condition *per se*. Five criteria (A to E) are used to assign a risk status, including two that relate directly to ecosystem condition. Criterion C deals with environmental degradation and is assessed based on the relative severity of decline in abiotic indicators over a specific ecosystem extent. Relative severity describes the proportional change in an indicator scaled between two values: a value describing the state of the ecosystem at the beginning of the assessment timeframe (0% change) and one describing a collapsed ecosystem state (100% change). The timeframe can be a 50 year period, or the period since 1750. Criterion D deals with disruption of biotic processes or interactions. The evaluation of criterion D follows the same procedure as with criterion C, but focuses on biotic variables rather than abiotic variables. (Bland et al. 2017)

Annex 5.2: SEEA Ecosystem condition typology

Introduction

The SEEA ***ecosystem condition typology (ECT)*** is a hierarchical classification for ecosystem characteristics and condition variables and indicators. Such a typology can establish a common language and a shared understanding, and increase comparability among different studies (assessments, countries, etc.). Furthermore, by creating a meaningful order among ecosystem condition variables and indicators, it can also be used as a template for selection and as a structure for aggregation. It is recognized that ecosystems and their characteristics are highly complex, and hence the SEEA ECT aims at a balance that meets the requirements for statistical classifications and is ecologically meaningful.

Different ecosystem types have different relevant characteristics, which should be described by different variables. Therefore, in order to facilitate communication, as well as comparisons and aggregation across ecosystem types, the ECT is universal, at least at the top level (i.e. it is expected to be relevant for all major ecosystem types), but also allows the incorporation of ecosystem-specific metrics at lower levels.

The SEEA ECT has seven classes as listed in Table 5.1. This classification can be applied for ecosystem characteristics, as well as for ecosystem condition variables and indicators, for which it is used to create a reporting and aggregation structure. The classification derives a set of ecosystem condition groups and classes with the common aim of being exhaustive (broad and inclusive enough to be able to host all variables and indicators that meet relevant selection criteria – see Annex 5.3), and mutually exhaustive (each metric can be assigned to a unique class).

The structure of the proposed groups and classes reflects a combination of long-standing ecological tradition (composition, structure and function, cf. Noss, 1990), theoretical considerations as discussed above and the findings in recent typologies including the classification of essential biodiversity variables (EBV), as outlined by Pereira et al. (2013); the ecosystem integrity typology proposed by Müller et al. (2005); the BESAFE/OpenNESS typology of the characteristics of 'natural capital' (Smith et al., 2017); and the MAES typology for the mapping and assessment of ecosystem condition in the EU (Maes et al., 2018).

It must be recognized that composition, structure, and particularly function are extremely broad concepts, interpreted in different ways by the different researcher communities. To avoid ambiguities, and to ensure the *mutual exclusivity* of the classes, there are detailed interpretations for each class, with a detailed discussion on boundary cases.

Description of ECT classes

The class **physical state characteristics** hosts the physical descriptors of the abiotic components of the ecosystem (soil, water, air…). Physical stocks that are typically being degraded (depleted) due to human pressures (e.g. soil organic carbon, water table level, impervious surfaces) are good choices, as they are sensitive to changes, and relevant for policy interpretation.

The class **chemical state characteristics** contains the variables and indicators related to the chemical composition of the abiotic ecosystem components. This typically involves the accumulated stocks of various pollutants in soil, water, or air, but only if the selection criteria are met (e.g. global atmospheric CO_2 concentration probably should not be seen as a condition metric). Similar to *physical state characteristics*, indicators should describe the state ("stocks" of pollutants) rather than the flows (emission of pollutants). This way both abiotic ECT classes accommodate major pressures in a way that is compatible with accounting (the pressures are related to the changes in the indicators).

The class **compositional state characteristics** comprises a broad range of 'typical' biodiversity indicators, describing the composition of ecological communities from a biodiversity perspective. This includes the indicators based on the presence / abundance of a species or species group, or the diversity of specific species groups at a given location and time. From a location-based perspective (required by spatial consistency) the distribution of a species also boils down-to species composition (local presence). Compositional metrics can characterize the presence / absence or abundance individual species, taxonomic groups (birds, butterflies), or non-taxonomic guilds (e.g. soil invertebrates, macro-zoobenthos). However, indicators based on highly specialist functional groups, where even data collection was performed from a functional perspective (e.g. pollinators, N-fixers, etc.) should be considered either as *functional state characteristics*, or as *ecosystem service indicators* (if they are tightly connected to a single specific ecosystem service). Abundance metrics of very large guilds (e.g. trees, phytoplankton) comprising entire ecosystem compartments should be considered as *structural state characteristics* (biomass, vegetation).

The class **structural state characteristics** primarily focusses at the vegetation and biomass of the sites, comprising metrics describing the local amount of living and dead plant matter (vegetation, biomass) in an ecosystem. This class includes all metrics of vegetation density and cover, either related to the whole ecosystem, or just specific compartments (canopy layer, belowground biomass, litter...). For marine and freshwater ecosystems this class can include chlorophyll concentrations, phytoplankton abundance, or plant biomass (e.g., seagrasses). There is some overlap between *compositional* and structural state metrics, particularly for foundation-species-based ecosystems such as mangrove, or where species groups and vegetation compartments coincide (trees on savanna, lichens on mountain rocks). Such cases should be registered in this class.

The class **functional state characteristics** should host simple summary statistics (e.g. frequency, intensity) of relevant ecosystem processes which meet the selection criteria (see Annex 5.x) and which are not already covered by other indicators. Ecosystem functions is a hugely diverse umbrella concept, which is used in highly different ways by the various research communities. Many of the characteristics that can be seen as 'ecosystem functions' can also be seen as a *compositional* (e.g. species abundances), *structural* (e.g. plant biomass), or *abiotic state descriptors* (e.g. surface albedo), or even as *ecosystem service indicators* (ES accounts). It is a good practice to avoid placing functional characteristics into this class whenever they can find a better home in another class.

The class **landscape and seascape characteristics** comprise the characteristics of ecosystem type mosaics, typically quantifiable at large (landscape, seascape) spatial scales. The diversity of ecosystem types in a landscape ('landscape diversity'), for example, can describe the integrity of landscapes at broader spatial scales, and also exerts influence on several ecosystem services (Verhagen et al., 2016). Metrics of landscape connectivity / fragmentation measure important landscape characteristics from the perspective of a specific ecosystem type (or group of ecosystem types). Landscape connectivity can be interpreted and measured very differently in terrestrial, freshwater, and marine biomes. Furthermore, in the case of ecosystem types, which themselves are 'mosaics' of relevant subtypes (e.g. a cropland with nested seminatural vegetation fragments), the abundance or the spatial pattern (connectivity) of these subtypes can also be hosted under this class. The proposed structure of condition accounts expects that indicators be linked to specific ecosystem types. This can be achieved by linking the landscape-level metrics (which were e.g. calculated with a moving window) to the local ecosystem type. In other words, the 'landscape diversity' of a forest should be interpreted as the diversity of the landscape in which the forest is situated.

Annex 5.3: Selection criteria for ecosystem condition variables

Introduction

Section 5.2 clearly distinguishes (1) ecosystem characteristics (i.e. major groups of system properties or components based on ecological understanding), and (2) the variables (and indicators) which are used to quantify them. Characteristics can be broad and abstract (for example, SEEA EEA lists water, timber, carbon and biodiversity as characteristics relevant for "basic resource accounts"), whereas variables (and indicators) should be concrete and specific as much as possible. Characteristics and variables can be seen as two hierarchical levels of structuring and organizing condition information. The selection procedure should address both stages. Adapting the recommendations of Niemeijer and de Groot (2008), the general procedure for the selection of ecosystem condition variables should include the following three steps:

- Defining the scope and the purpose of the study (ecosystem, accounting goals...),
- Identifying key characteristics (ecosystem components and processes),
- Selecting the best indicators for the selected characteristics.

The identification an adequate set of condition variables can be a complex and challenging process. Indicators need to be scientifically credible, responsive to user needs (salience), and be perceived as such by their end users (legitimacy, Cash et al., 2003). From a policy perspective, the success of an indicator resides in its utility for policy actors, influence on policy processes, and impact on policy outcomes (Bauler, 2012). There are many papers in the scientific literature that aim at supporting and standardizing the process of identifying and selecting indicators with criteria and recommendations (e.g. Dale and Beyeler, 2001; Niemeijer & de Groot, 2008; Giannetti, 2009; Kandziora et al., 2013).

There are several criteria that potential variables must meet in order to characterize the condition of ecosystems in a way that complies with accounting principles, is policy-relevant, and is also meaningful from a biophysical perspective. The selection criteria were introduced in Section 5.2 of this chapter and summarised in Table 5.2. This annex gives a comprehensive overview on all potential selection criteria that should be observed in order to create an adequate set of ecosystem condition indicators in a SEEA context. Following Niemeijer & de Groot (2008) we distinguish two types of selection criteria: *individual criteria*, which can be used to appraise the relevance or usefulness of each ecosystem characteristic or indicator proposed; and *ensemble criteria*, which need to be applied to the whole set of candidate indicators (e.g. to ensure that there are no gaps or double counting).

Description of criteria for individual metrics

The criterion of **relevance** implies that the selected condition metrics should address those characteristics of the ecosystems that are most relevant from the perspective of the *fundamental purpose* underlying the condition accounts. With an instrumental perspective (see also DP 2.1) *those characteristics should be selected, which exert the most influence on the capacity of the ecosystems for providing multiple ES*.[7] On the other hand, from an intrinsic perspective a good scientific understanding on what constitutes ecological integrity can also be used as a starting point to determine which characteristics need to be considered relevant.[8]

[7] The criterion of relevance could be established by well-designed systematic reviews exploring the relationships between ecosystem characteristics and ecosystem services (e.g. Verhagen et al., 2016; Czúcz et al., 2017; Schwartz et al., 2017; Smith et al., 2017). There is a high amount of primary research studies that test the relationship between a particular ES and a particular ecosystem characteristic in a specific context (ecosystem type), but general syntheses are still largely missing.

[8] As long as a widely applicable and accepted general synthesis of ES~EC relationships is not available (see previous footnote), a broadly agreed typology of ecosystem condition indicators reflecting long standing ecological knowledge can be used as a

The relatively abstract criterion of '**state orientation**' requires that ecosystem condition variables should describe the state of the studied ecosystem as much as possible.[9] Most ecosystem characteristics don't have a single 'default' formulation (definition/quantification approach)[10]. If there is a choice between two alternative ways (variables) for quantifying a relevant system characteristic, the one which conforms more to the idea of 'state' is the one which should be preferred.

The criterion of **framework conformity** is of key importance for the integrity of the whole assessment. According to this criterion, each aspect of the studied system should only be described under a single component of the SEEA EEA conceptual framework. Characteristics that can be better considered under *ecosystem extent* (e.g. forested area or deforestation) or *ecosystem service* (e.g. carbon sequestration) should be handled there and only there. If such characteristics are re-considered as condition variables, that might lead to double counting and user confusion, and thus can discredit the whole assessment.

The criterion of **spatial reference** means that the variables need to be linked to a specific location (mapped). More specifically, all candidate variables have to be interpretable over *any area* that is (1) larger than a predefined minimum area ('*spatial grain*'), and (2) is covered by one of the ecosystem types for which the variable makes sense ('*thematic domain*'). The grain and the thematic domain of each variable should be included in their definition. Ideally, the whole accounting should have a harmonized spatial grain and the definition of the variables should respect this grain. For example, a large grassland is handled as an ecosystem type, whereas a small ('sub-grain') grassland is considered as a part of the embedding ecosystem type (e.g. cropland) with the 'density' of such embedded fragments considered as a condition attribute of the embedding ecosystem type).

Temporal reference implies that variables are sensitive to change and linked to a specific time period (*temporal grain*), which should be regularly in SNA / SEEA EEA, e.g. every year or every 5 years. Biophysical considerations also suggest that the grain should cover at least one full annual cycle which is the key periodical cycle for the studied system. Sensitivity to change should also be considered (with respect to this temporal grain), so that condition would be reasonably variable across a few time steps (i.e. *quasi-constant* or *extremely variable* candidate variables should be excluded or reformulated). This means that for data streams with relatively fine temporal resolution (e.g. remote sensing data) the precise definition of the condition variables should involve some sort of 'temporal aggregation', e.g. in the form of appropriate statistical aggregation functions (central tendencies or extremities, e.g. mean annual values, annual maxima, etc.). Defining the timeframe and time resolution is important for selecting variables: for instance, to estimate change over 50 years with data every 5 years, the most useful variable may be different than a variable which measures intra-seasonal variations of an ecosystem characteristic.

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surrogate. To this end the typology has to be considered an indicator template (i.e. as a shortlist of characteristics which are considered relevant, and thus have to be included into the condition account, see also Chapter 3).

[9] The DPSIR framework distinguishes pressures (influences, inputs) and responses (consequences, outputs) from state descriptors. In system science, state is considered to be a set of variables that describe enough about the system to determine its future behaviour in the absence of any external forces (Palm et al., 2005). Furthermore, a system analysis perspective, can also help to justify/interpret the criteria of relevance & parsimony, as the set of 'state' indicators of a system are expected to "describe enough about the system to determine its future behaviour" (Palm et al., 2005). As in the context of ES accounting / assessments the key output ("future behaviour") of the studied system is the portfolio of ES generated, it is important that the 'state variables' describing the system would capture everything that can influence this portfolio.

[10] Most of the (eco)system characteristics can be measured/quantified in several potential ways. There can be many potential reasons for this: e.g. the characteristic can be abstract & ambiguous (e.g. biodiversity, use intensity), or difficult to measure (e.g. NPP, grazing intensity) or just too highly fluctuating (water availability, vegetation cover) which needs to be 'averaged' somehow (and there are multiple options...) The arising options can lead to different quantitative measures (=indicators) which just indicate the same ecosystem characteristic.

Feasibility means that variables should be covered by (potentially) available data sources over large areas. This implies that those characteristics that are difficult to measure or are in any way unfeasible to be covered by data in the foreseeable future should be avoided.

According to the criterion of **quantitativeness** variables should be measured at a well-defined quantitative scale, which allows for meaningful comparisons and change detection. Variables should ideally be measured at a ratio/interval scale or at least at an ordinal scale (sensu Stevens, 1946). Attributes measured at a categorical/nominal scale should preferably not be used as condition variables, unless they can be reformulated to an ordinal/interval/ratio scale (e.g. by using scores/weights, or by being quantified as the 'share' of a relevant subtype over a larger area).

The concept of **reliability** is linked to the uncertainties concerning the variables. Suitable variables should rely on data that are measured in an objective and standardized way. Primary (measured) data should be preferred to modelled/derived data, which always rely on a number of assumptions, contain inherent errors, and are thus more prone to being criticized or disputed.[11] Modelled data can change even retrospectively if the modelling technique is updated. In the formulation of the variables, subjective elements should be avoided as much as possible, and if unavoidable (e.g. scores used for weighting 'components' of a composite indicator) they should rely on a broad consensus of 'experts' in a clearly documented way. Data streams should ideally be resistant to malicious tampering/manipulation.

Indicators should by definition have a '**normative**' interpretation, i.e. they should be able to distinguish what is 'good' or desirable from what is 'bad' or undesirable -- preferably with general consensus. This distinguishes indicators from simple variables, which don't have an agreed normative interpretation associated to them (Heink & Kowarik., 2010)[12]. Assigning agreed reference values to variables is a frequently used technique to make them indicators, and any deviation from the reference value is seen as undesirable. Ideally, desirable and undesirable should lie at the opposite ends of the scale of an indicator, so that there is a monotonous 'quasi-linear' relationship between the variable and the underlying human value judgement (i.e. an increase in the indicator value should always mean a better condition, and the same increase in the indicator value should always mean approximately the same degree of 'improvement' in the condition -- at all parts of the scale). The criterion of normativity also implies that indicators should be selected / constructed in a way that approximates this ideal situation as much as possible[13] (as this can allow easier policy interpretations, and more straightforward aggregation procedures).

Finally, good variables should be as **simple** as possible (but not any simpler). If every other criterion is ensured, simpler variable (allowing easier policy interpretation and more powerful messages) should be preferred over more complex/abstract metrics.

Ensemble criteria

The remaining two criteria do not focus so much on the characteristics of the individual indicators, but on the whole indicator set. **Comprehensiveness** implies that all relevant characteristics of the ecosystems are covered by appropriate variables, so that the set should embrace all major 'aspects'

[11] This does not involve primary data cleaning/harmonization/transformation operations, such as spatial/temporal interpolation/aggregation, or quality control (noise reduction) techniques. Such pre-processed data can be more accurate than non-transformed ones.

[12] In this sense variables are 'neutral', and 'neutrality' can also be defined as the lack/opposite of normativity. Neutrality (in this sense) can be a useful property of variables in some applications, but in the frame of condition accounts normative variables (i.e. indicators) seem to be more useful than neutral variables.

[13] Nevertheless, other criteria (e.g. simplicity) can be in conflict with this one, and even some of the most widely used indicators (e.g. human body temperature as a health indicator) may not have a single linear normative interpretation (i.e. an increase in the temperatures is bad above 36 °C, but it is good at lower parts of the scale: fever vs. hypothermia).

of the studied system. The set of indicators should be checked for comprehensiveness, and all system characteristics which are known to be relevant but are not covered adequately by available data sources should be highlighted as data gaps. The identification of such information gaps can help in guiding future research activities.

Parsimony or complementarity means that overlapping and/or correlated indicators should be avoided. The main purpose of the ensemble criteria is to ensure that all relevant and available information would be covered by as few variables/indicators as possible. Many times there can be correlations between seemingly unrelated variables describing different system aspects (and listed under different ECI headings, see Chapter 3), which are generated by the internal mechanisms of the studied system. Correlations can also be introduced by technical artefacts (e.g. by inconsistent reuse/re-labelling of data streams). In case of 'correlation conflicts', the most appropriate (relevant, simple, reliable, framework conformity, etc) candidate should be chosen following the criteria for individual indicators. All kinds of correlations in the final indicator set imply a high risk of confusion and (particularly the technical artefacts) can lead to a loss of credibility.

Annex 5.4: Ancillary data for ecosystem condition measurement

Introduction

Section 5.2 noted the relevance of a range of ancillary data to support the measurement of ecosystem condition. This annex describes various types of ancillary data. Generally speaking, these types of data do not satisfy the criteria (described in Annex 5.3) for selection as ecosystem condition variables consistent with the SEEA ecosystem condition typology (ECT) (see Annex 5.2). Many of these ancillary data can be compiled following other statistical systems including the SEEA Central Framework and the Framework for the Development of Environment Statistics.

Groups of ancillary data

Ecosystem extent (EBV E2): The extent of the main ecosystem types should definitely go under the *ecosystem extent* component of the SEEA framework (criterion: *framework conformity*). The extent of a 'minor' ecosystem types can be registered in the ECT class *ecosystem-specific landscape characteristics*, if necessary.

Accessibility: Distance from roads or human population centres appears in a high number of condition accounts, yet they do not necessarily meet some of the selection criteria. Such 'accessibility' indicators can be seen as a factor behind ES demand and may be considered as something external to the studied ecosystem (violating *framework conformity*, *state orientation*, or even *system scope*). *Normativity* can also be an issue: if an ecosystem becomes more accessible (e.g. there is a new highway), would we like to see this as a condition improvement or degradation? The density of human populations or road networks (e.g. forest roads, or mountain trails) can also considered as a pressure/management indicator (characterizing the 'infrastructure' for ES extraction).

Protected areas: Administrative land designations (including the status and degree of nature protection) do not reflect the state of an area, but rather a human response to degradation or perceived land value. Using such indicators in condition accounts violates *state-orientation* (see also section 5.4).

Pressures: As discussed in section 5.4, 'raw' pressure indicators (e.g. pollutant loads, habitat loss) should be avoided and the underlying 'degradable stocks' (e.g. pollutant concentrations) should be used instead as condition indicator. (If this is not possible, and pressures are still used as a proxy, then they should be assigned to the same ECT class that the underlying degradable stock would belong to.)

Natural resource management: Ecosystem management (e.g. grazing, felling, fishing, agriculture) is not necessarily considered as an internal part of the studied ecosystems (*system scope*, *state orientation*), so such metrics should not be considered in condition accounts (see also section 5.4). If there is an underlying stock that is being extracted (timber, fish) this stock can be considered under the ECT class where it best fits (as a *compositional*, *structural*, or *functional characteristic*). (In the case of heavily transformed ecosystems management can exceptionally be considered as an 'anthropogenic' disturbance regime, which can then be characterized with its intensity as a *functional state characteristic*).

Species population phenology (seasonality): The phenological phase of species populations can be challenging to be integrated across *temporal* grain units, and lacks *normativity*. Timing (of the events) is not necessarily considered as 'state', as a 'phase shift' by itself does not influence functioning. In the cases when asynchronous timing shifts create a relevant net impact on functioning (e.g. an earlier greening and a later leaf-fall creates a longer vegetation period) than it is this net effect which should be captured by a state indicator (e.g. more biomass, different species).

Stable environmental characteristics: Environmental variables that are virtually constant (e.g. climate, local topography (slope, aspect), or geology) do not meet the criterion of *temporal reference*, and in many cases they also lack *normativity*. Some of these variables may not be constant on longer timescales, and climatic variables, in particular have started to change due to anthropogenic climate change. Nevertheless, climate itself is rather external to the ecosystems (*scope*, *state-orientation*), and the ecological impacts of climate change are already covered by the classes listed above. In addition, climatic variables are very well monitored by a number of international conventions and data exchange processes, so it might be reasonable to keep the ecosystem condition accounts for ‘more ecological’ variables.

Pre-aggregated indexes: Data collected and processed for various policies are often available in a highly aggregated format. This aggregation may combine data from several ECT classes, but other data types that are irrelevant or problematic for ecosystem condition accounting may also be involved. Driven by the necessity to reuse what’s already available, such pre-aggregated indicators are often considered in practical ecosystem condition accounts. Such data might violate high numbers of criteria (e.g. *reliability*, *spatial & temporal reference*, *state orientation*, and *framework conformity*). If these violations are minor, then the pre-aggregated index should be considered in the ECT class where it most logically belongs. Pre-aggregated indices covering multiple ECT classes should be avoided, if possible. The ideal practice would be to add all relevant characteristics individually, and perform the appropriate aggregations within the condition account itself. One of the main functions of the ECT typology is to provides a standardized aggregation scheme that can be meaningfully used across countries, continents and ecosystem types. Such ‘overarching’ pre-aggregated indices might violate this function.

Certificates, audits: Evaluation by companies or organizations (e.g. the ‘blue flag’ certificate for EU beaches, or the ‘green flag’ certificate for UK urban parks) cannot be seen as ‘original’ measurements (*reliability*), and such audits need to rely on primary (socio-) ecological data. Certificates come with costs and they need to be applied for, thus the absence of a certificate does not mean that the location in question would not meet the necessary qualifications (*reliability*, *state orientation*). If such data are still considered as necessary, they should be classified under the ECT class where they best fit. Similar to pre-aggregated indicators, in the case of certificates the ideal practice would also be to encode all relevant characteristics individually in the condition account, and create appropriate aggregated indices there (as a substitute of the audit process).

Annex 5.5: Options for establishing natural reference conditions (1-4) and anthropocentric reference conditions (4-9)

Reference / anthropocentric condition based on:	Strengths	Weaknesses	Examples of reference conditions
1. Stable or resilient ecological state maintaining ecosystem integrity	The optimum baseline. Can be assessed by long-term monitoring. Can be defined by a level of tolerable change or risk.	May be difficult to define. Reference might change due to global change or as scientific understanding improves.	Pristine or natural state
2. Sites with ecosystems with minimal human disturbance	Ecosystem variables can be measured on least disturbed reference sites and can deliver reference levels for variables and indicators. Statistical approaches based on current data collections of ecosystem variables can be used to screen reference sites based on knowledge about pressures.	Most, if not all, ecosystems are under some form of human pressure (in particular climate change). For some ecosystems it is no longer possible to find reference sites. Can fail to recognise spatial and temporal variation, in particular in cases where only few reference sites remain that are not evenly distributed (e.g. old growth forests, wilderness, undisturbed marine habitats), and thus can be spatially inconsistent.	Undisturbed, minimally or least disturbed state/condition Many examples for surface water ecosystems (reference condition is defined in the EU Water Framework Directive
3. Modelled reference conditions	Can be modelled globally and can incorporate climate change / emissions scenarios.	Modelling usually does not involve all of the selected condition variables. Requires assumptions to establish reference levels for condition variables, (eg the scientific debate on the role of megafauna and early humans on potential natural vegetation) Unclear how to assess semi-natural systems with often high levels of species diversity	Potential natural vegetation (Hickler et al. 2012) Maximum ecological potential (possible based on expert judgement) Theoretical stable state of an ecosystem Best attainable state.
4. Statistical approaches	Methods can be applied consistently across variables, eg normalizing with the maximum and minimum values of available data.	Relies on data for the range in values at the current state, which can create spatial inconsistencies and a shifting baseline. Difficult to scale conditions at levels outside the range of the available data.	Stochastic frontier analysis Women's Peace and Security (WPS) Index (Kirby & Shepherd, 2016)
5. Historical reference condition (Setting a baseline period against which (past, present or future) condition can be evaluated)	A common baseline for climate and biodiversity science and policy. Shows the magnitude of loss of biodiversity. Can also be reconstructed based on species lists (paleo-ecology), or paleo-climate indicators.	Data on ecosystem characteristics are usually not available (in particular for marine ecosystems). Data available are not representative. Degree of human impacts varied in time across continents.	Pre-industrial state (1750) 1500 (Biodiversity Intactness Index for modelling) Pre-intensive land use (where the date may vary in different countries) Earliest date that data are available.
6. Contemporary reference condition	Can be used to assess the condition of novel ecosystems or ecosystems heavily modified by humans	Reliance on contemporary data in evaluating changes can result in a shifting baseline.	1990 (Kyoto protocol for GHG emissions)

(Setting a baseline year against which (past, present or future) condition can be evaluated)	Can be based on current data of ecological characteristics and maximum values or statistical approaches such as percentiles.	Appropriate dates differ for different indicators and ecosystem types. Different starting dates in different regions creates inconsistencies. Condition of variables about a single point in time can be highly variable. Difficult for scaling conditions at levels which are higher than the reference Open to policy influence and are often changed. Contemporary baselines diverge greatly from pre-industrial era baseline conditions	1970 (RAMSAR, IPBES global assessment) Date for the beginning of an accounting period.
7. Stable state or sustainable socio-ecological equilibrium	Applicable for a range of human-modified ecosystems.	Difficult to define objectively. Definition of not undergoing degradation in terms of ecosystem characteristics or supply of ecosystem services, may be difficult to quantify.	Long-term agricultural production systems
8. Prescribed levels in terms of legislated quality measures or expert judgement	Provides a mechanism for enforcement	Can be subjective and influenced by policy. May differ between countries, ecosystem types and indicators.	Pollution levels
9. Target levels	Can reflect preferences for a particular use of an ecosystem taking into account social, economic and environmental considerations. A threshold value where there is evidence that an indicator value above or below the threshold represents sub-optimal ecosystem condition. A reference level quantifying an undesirable state can be required to define the zero end of the normalized scale, for example, where the ecosystem is no longer present or functioning. Linked to management applications and policy	Can be subjective and influenced by policy. Can be changed over time. Often differ between countries and may not be consistent for all ecosystem types and indicators	Species recoveries Emissions reductions

Reference condition based approaches are applied in the following ways in these selected international conventions:

UNFCCC United Nations Framework Convention on Climate Change

- Pre-industrial (before 1750) used as the baseline for atmospheric CO_2 concentration before human influence. However, change in land use and human influence on ecosystems occurred before 1750 in many places;
- Baseline for emissions reduction targets started at 1990 but has shifted since, and years differ between countries.

UNCCD United Nations Convention on Combatting Desertification

- The baseline for land degradation is the initial value of the indicators (i.e. at the start of the time series);
- Countries can set their own baseline;
- The reference condition is set to equal the target level. Generally, it is advisable to clearly separate these two states and decouple the reference condition from policy targets.

CBD Convention on Biological Diversity

- The CBD has no agreed reference condition, but progress is assessed against targets relative to the baseline years (2000, 2010, …) of each policy cycle.

IUCN Red List of Threatened Species and Ecosystems

- Baseline of pre-industrial (before 1750)
- For one parameter (generation length) the guidance on red lists refers to using a "pre-disturbance" state to avoid a shifting baseline effect (only for one criteria)

Annex 5.6: Aggregation of ecosystem condition indicators

Data dimensions

The aim of aggregation is to generate summarized information from a high number of data points. For multidimensional data structures several different types of aggregation can be distinguished. The types of the aggregation can be related to the 'dimensions' of the data structure. The data behind the SEEA ecosystem condition accounts has the following main data dimensions:

Spatial: the most elementary spatial units are the *ecosystem assets* (EA) as defined in Chapter 3. The size of these units determines the spatial resolution of the ecosystem accounts. Further relevant levels of spatial resolution are *ecosystem types* (ET, which denotes all EAs that belong to the same ET within an EAA); and the ecosystem accounting areas (EAA). There can be several EAAs, which can be organized into further hierarchical levels (e.g. municipalities nested in regions nested in countries).

Temporal: the most elementary temporal units are the years. The use of temporal units in the SEEA ecosystem condition accounts follows the standard accounting practice (annual records with optional multiannual / decadal periods).

Thematic: the elementary "thematic units" of the SEEA data structure are the ecosystem condition *variables* and *indicators*. Nevertheless, thematic aggregation should always start out form the rescaled forms of the variables (i.e. the *indicators*, I), which are dimensionless, and have a common scale [0, 1]. The indicators can be grouped into *ECT classes* and *groups*. Within each ET there is a different list of relevant indicators, but the ECT classes and groups are the same for al ETs. Accordingly, the relevant levels of thematic resolution are the indicators (discussed above), sub-indexes (SI, metrics describing whole ETC classes or groups within an ET); ECI indexes (describing the condition of an ET in an EAA); and OECI indices (describing the overall ECI of multiple ETs in an EAA).

Ecosystem types thus play a key role in terms of both structuring the selection of variables and indicators and reflecting the within an EAA that is a focus of recording in the condition accounts.

Types of aggregation

This data structure creates options for several types of aggregation (Table A5.6.1), many of which were already discussed in detail in Chapter 5.3.

Table A5.6.1: Most important types of aggregation for the SEEA EEA ecosystem condition accounts

	Type	From	To	Scope	Method
Basic aggregations (discussed in Chapter 5.3)					
1	spatial	EA (or BSU)	ET	any variables, indicators or sub-indexes	area-weighted arithmetic mean
2	thematic	I	SI	any EAs belonging to the same ET	(weighted) arithmetic mean
3	thematic	SI	ECI	any EAs belonging to the same ET	arithmetic mean
4	spatio-thematic	ET/ECI	EAA/OECI	any ETs belonging to the same biome & reference condition type (natural, anthropogenic...)	area-weighted arithmetic mean
Complementary aggregations					
5	spatial	EAA	EAA	any variables, indicators, sub-indexes, or indexes	area-weighted arithmetic mean
6	spatio-thematic	ET/I	EAA/I	any ETs belonging to the same biome & reference condition type (natural, anthropogenic...)	area-weighted arithmetic mean

7	temporal	Temporal aggregations are expected to follow exactly the same rules as such aggregations can be done in SNA accounts – ecosystem condition metrics are not different in this respect.

From a **temporal** perspective, ecosystem condition accounts are completely similar to SNA accounts, so we will focus on the spatial and thematic dimensions of aggregation here.

Thematic aggregation assumes that different indicators can compensate for each other. Consider two forest condition indicators: the number of forest bird species and the amount of dead wood. Increasing values of both indicators are associated to increasing condition. Both indicators can however, have, different directions of change. Assume forest birds are declining but dead wood is increasing. Thematic aggregation might lead to the conclusion that the forest condition remains stable.

The special type '**spatio-thematic**' refers to aggregation across ecosystem types (ET), which always has both a spatial and a thematic aspect. The creation of the headline OECI indicators shown in Chapter 5.3 involves such 'spatio-thematic' aggregation. This step is presented in Table A5.6.2 (in a structure similar to the accounting tables presented in Chapter 5.3), and several important aspects of this step are discussed below.

Table A5.6.2: Overall ecosystem condition index account for an EAA

	Opening condition			*Closing condition*		
	ECI	*Area (km2)*	*ECI*area (km2)*	*ECI*	*Area (km2)*	*ECI*area (km2)*
Seminatural ecosystems						
Seminatural terrestrial						
T2 Forests	55%	10000	5500	50%	9000	4500
T4 Grasslands	65%	4000	2600	80%	...	
FT1 Wetland (weight:50%)	70%	1000	700			
Overall	**59%**	**15000**	**8800**			
Seminatural freshwater						
F1-F2 Rivers and lakes	40%	2500	1000			
FT1 Wetland (weight:50%)	70%	1000	700			
Overall	**49%**	**3500**	**1700**			
Seminatural marine						
...	--	--	--			
Overall seminatural ECI	***57%***	***18500***	***10500***			
Anthropogenic ecosystems						
Terrestrial						
Urban						
Cropland						
Overall ECI						
Freshwater						
...						
...						

Overall anthropogenic ECI						

As ETs can be fundamentally different, aggregation across them is not always meaningful and recommended. As emphasized in Section 5.3, aggregation across ETs from different realms (e.g. marine and terrestrial) or with different reference conditions (natural vs. anthropogenic) is not recommended. In principle, it is a good practice to set up a couple of predefined "aggregation groups" among all the ecosystem types (e.g. marine, freshwater, terrestrial seminatural, terrestrial anthropogenic), and to perform the spatio-thematic aggregation only within these "aggregation groups". This will result in a small number of headline OECI indices for high level policy applications. By eliminating the aggregation between seminatural and anthropogenic ETs a high number of measurement artefacts, like urbanization leading to an increased OECI can be avoided.

The system presented in Table A5.6.2 also provides an option for treating transitional ecosystem types: they can be shared between the major biomes they belong to (weights should be documented). For each ET, ECI is a [0,1]-scale metric of its overall quality, while the total area of the ET expresses its quantity. This makes it possible to express the overall "condition value" of the ecosystem stock as its "quality-corrected area", using the product ECI and area. This approach relies on the Natural Capital Index (NCI) approach[14] which can be easily communicated and understood, and has several favourable statistical properties (Czúcz et al., 2012)[15]

Based on the SEEA EEA ecosystem condition data structure, further meaningful types of aggregation can be created, which can be used to meet to meet common user needs. These are indicated as "**complementary aggregations**" in Table A5.6.1. For example, spatial aggregation from a smaller EAA to a larger EAA is a relatively straightforward operation, which can be applied to almost any condition metric (variables, indicators, indices).

The fact that there are (potentially) several **'crosscutting' variables** and indicators that are shared between multiple ETs can be used to perform spatio-thematic aggregation (6) also at the level of the variables and indicators. Nevertheless, in the case of the rescaled variables (indicators) it is important that the reference levels should also be identical – otherwise the cross-ET aggregation can be misleading and should be avoided. Technically it is also possible to perform spatio-thematic (6) aggregation at the level of ECT classes (i.e. sub-indices). Nevertheless, given that for each ET, the sub-indices are composed of different variables, the same care should be taken with this type of aggregation as it was recommended above for the OECI indexes (4).

Aggregation functions and weights

In principle there are several choices for aggregation functions for each type of aggregation operation that can be distinguished. These choices involve several function 'families' (e.g. arithmetic mean, geometric mean, minimum or maximum operators, etc.), and an optional weighting that can fine tune the operation. Many of these options are widely used in established environmental indicator frameworks. For example, the Human Development Index applies arithmetic mean for sub-indices, followed by a geometric mean for the overall index. A 'precautionary' one out all out approach (where a single declining indicator means degradation whereas improvement is based on an ensemble of increasing indicators) is used in the assessment of the conservation status linked to the EU Habitats and Birds Directives.

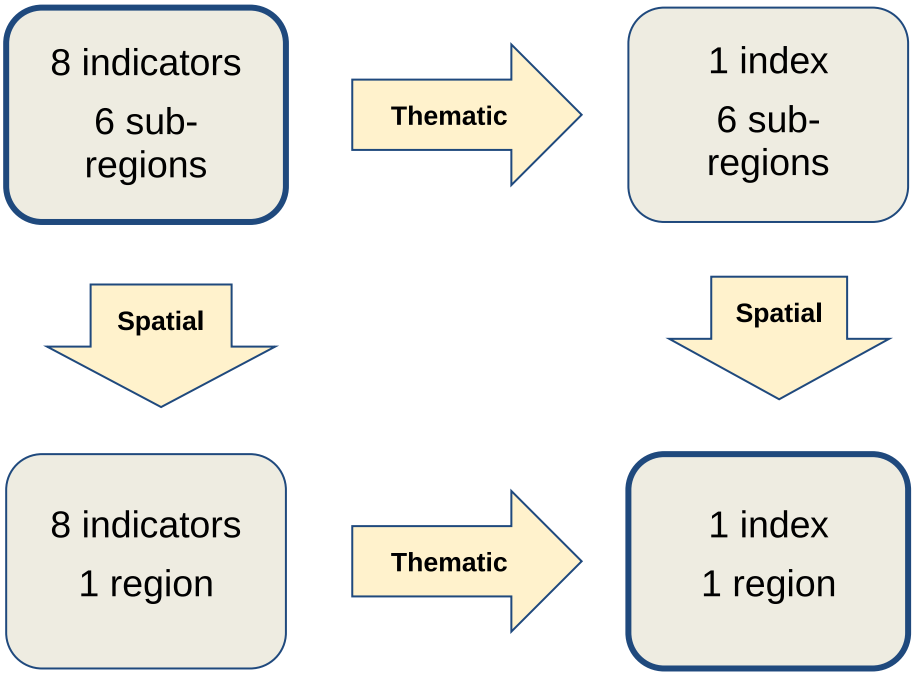
To avoid fundamental flaws and ambiguities in the data streams, it is important that the aggregation operations listed in Table A5.6.1 would be associative and commutative. In simple words, this means that subsequent operations should lead to the same result irrespective of the order in which these

[14] https://ec.europa.eu/environment/beyond_gdp/download/factsheets/bgdp-ve-nci.pdf

[15] https://www.google.com/url?q=https://www.sciencedirect.com/science/article/abs/pii/S1617138111000872

operations were performed. If, for example, there are 48 numbers which stand for 8 indicators in 6 subregions, and these are aggregated to a single index for the whole region, then we should get the same figure both if we do a spatial aggregation followed by thematic aggregation, and if we do the aggregations in the opposite order (Figure A5.6.1). To achieve this mathematical property, different 'families' of aggregation functions (e.g. median, arithmetic mean, geometric mean, etc.) must not be mixed. Another relevant expectation towards spatial aggregation is that differences in area (extent) should be reflected in the aggregated value as well, which can only be satisfied with area-weighted arithmetic mean. The combination of these two criteria means that in the SEEA EEA system all aggregations need to be performed using arithmetic means, optionally with the inclusion of weights.

Figure A5.6.1: An example where the combination of two aggregations should lead to the same result, irrespective of the order of the steps (aggregation commutativity).



The use of weights can determine the relative importance of each indicator to an assessed overall condition of the ecosystem. All spatial and spatio-thematic aggregation steps should rely on weighting by area. Nevertheless, for thematic aggregations the use of weights should have a scientific rationale. In particular, any applications of preferential weighting (expert judgement about relative importance of the metrics) should be based on a broad consensus, and clearly justified and documented. For instance in forests, the percentage of sick trees, measured by defoliation, can be considered more relevant than tree species diversity to understand the current condition of a forest. If there is agreement on the weight or relative importance of condition indicators, these weights can easily be built into an aggregation scheme. In lack of substantial reasons an equal weighting system should be used.