DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS
STATISTICS DIVISION
UNITED NATIONS

System of Environmental Economic Accounting

SEEA EEA Revision

Working group 2: Ecosystem condition

Discussion paper 2.1: Purpose and role of ecosystem condition accounts

final version

Revised version: 5 September 2019

Recommended citation:
Keith, H., Maes, J., Czúcz, B., Jackson, B., Driver, A., Bland, L., Nicholson, E. (2019). Discussion paper 2.1: Purpose and role of ecosystem condition accounts. Paper submitted to the SEEA EEA Technical Committee as input to the revision of the technical recommendations in support of the System on Environmental-Economic Accounting. Version 5 September 2019. 50 pp.

Research area #2: Ecosystem condition

Discussion paper 2.1: Purpose and role of ecosystem condition accounts

Lead authors: Heather Keith, Joachim Maes, Bálint Czúcz
Contributing authors: Bethanna Jackson, Amanda Driver, Lucie Bland and Emily Nicholson

Contents

The SEEA EEA revision process

Ecosystem condition is defined in the SEEA EEA as the overall quality of an ecosystem asset in terms of its characteristics (United Nations, 2012).

How do we measure and report on the condition of ecosystems in an ecosystem accounting framework? Addressing this question means establishing a common definition of ecosystem condition, selecting suitable indicators of condition, evaluating the actual condition of an ecosystem against a reference, and providing an overall, comparable condition score for reporting or accounting. It also requires a further understanding of the relationship between the ecosystem condition, biodiversity and the delivery of ecosystem services as well as knowledge about the pressures (or in a broader sense the drivers of change) that continue to impact ecosystems.

The SEEA EEA Technical Recommendations (United Nations 2017) do not yet provide definitive advice on how to address these several challenges when reporting ecosystem condition in condition accounts. These challenges have been addressed in a Revision Issues Note for the Ecosystem Accounting Revision 2020 (United Nations, 2018) which recommends providing further guidance on ecosystem condition.

This paper is part of a series of discussion papers on ecosystem condition. It describes the current state of knowledge, suggested progress and options for implementation. The objective of this discussion paper is **to develop a framework for an inclusive account of ecosystem condition derived from an ecological understanding of the ecosystem upon which definitions, concepts and classifications are based.** The framework encompasses intrinsic and instrumental values, ecocentric and anthropocentric worldviews, and different outputs to be produced for different purposes and uses. Two additional papers are part of this series: a review paper of existing ecosystem condition accounts (discussion paper 2.2) and a paper developing a typology for ecosystem condition variables and criteria for their selection (discussion paper 2.3).

These discussion papers have been developed by a working group established as part of the revision process. The working group on ecosystem condition is one of five working groups for the four research areas (RAs) identified in the Revision Issues Note: RA1 focuses on spatial units, RA2 on ecosystem condition, RA3 on ecosystem services and RA4 on valuation.

1. Introduction

Ecosystem condition is a foundational component in the ecosystem accounting framework. It establishes the link between ecosystem assets, their quantity or extent, changes in assets over time and ecosystem services, that is, the stocks and flows of benefits derived from the stocks. Using ecosystem condition as a quality descriptor of ecosystem assets, together with ecosystem extent as a quantity descriptor, the link between stocks and flows can be established in a way that is compatible with the internal logic of the System of National Accounts.

Use of ecosystem condition and related concepts within an accounting standard requires standardised definitions, criteria and classifications. However, flexibility and inclusiveness in these standards are necessary for the international SEEA EEA framework, given the range of ecosystem types globally and potential uses (and users) of SEEA EEA accounts. Moreover, the purposes or objectives of ecosystem condition accounts also need to be explored, as these underlying reasons highly influence the selection of methods for implementation, and the interpretation and applicability of the accounting results. Data should be collected and presented in ecosystem condition accounts based on the principles of comprehensiveness and objectivity. Subsequent analysis and interpretation of these data can be aimed at specific goals or policies.

The concept of ecosystem condition and the general approach of characterizing ecosystem assets with relevant condition indicators were described in the SEEA EEA 2012 (UN et al., 2014) and its Technical Recommendations (UN 2017). Nonetheless, different approaches to ecosystem condition accounting have been used to date, including concerning some fundamental aspects, like purpose, definition and fields of application (see discussion paper 2.2). This variety has led to uncertainty about how these accounts should be developed and their place in the ecosystem accounting framework.

A major, but mostly hidden, source of divergence derives from varying perspectives about the purpose of assessing ecosystem condition in terms of quantifying values to assign importance to different characteristics. The purpose can be to represent **intrinsic values** where ecosystem condition is understood as the integrity of the ecosystem in terms of its structure, function and composition, and the intactness/degradation of the ecosystem in terms of ecological 'distance' from an initial or reference condition. The purpose can also be to represent **instrumental values** where ecosystem condition is understood as the capacity to supply specific ecosystem services, with both use and non-use values, and as such has a more utilitarian approach. This value choice is fundamental, as it can influence key decisions during the implementation and interpretation of the condition accounts.

An inclusive framework for ecosystem condition accounting that encompasses these different values will help to reconcile different views from different disciplines and thus encourage a greater range of participants in the development, use and application of accounts. Limited application of ecosystem accounts in real-world examples to support environmental policy has been achieved to date. In the case of ecosystem condition accounts, this is partly because relatively few such accounts have been developed. A contributing factor is the lack of acceptance of the ecosystem accounting approach by a range of disciplines, particularly ecologists, some of whom consider accounting as ‘commodifying nature’. A broad and inclusive definition of ecosystem condition may encourage greater participation. This includes intrinsic and instrumental values, ecocentric and anthropogenic worldviews, and the application of condition accounts in terms of biophysical metrics that do not necessitate conversion to ecosystem services or monetary values.

In the Revisions Issue Note for the Ecosystem Accounting Revision 2020 (UNSD 2018), ecosystem condition was identified as a research area, with the characteristics and indicators of ecosystem condition identified as a revision issue requiring conceptual work and specific testing and experimentation. The research area of ecosystem condition was discussed as one of the work streams at the UNSD SEEA EEA revision 2020 Forum of Experts in New York in June 2018.

This Discussion Paper supports the Revision 2020 process by addressing the following issues:

(i) Developing a generalized model or structure of characteristics and indicators of condition for different ecosystem types;

(ii) Determining which characteristics are relevant to monitoring condition;

(iii) Determining whether non-ecological characteristics, such as land use and management practices and pressures, should be included in condition;

(iv) Investigating types of indicators that are most relevant for different characteristics, including aggregated indices;

(v) Assessing the role of indicators of biodiversity (including genetic, species, ecosystem and functional diversity);

(vi) Providing advice about reference conditions, in terms of a conceptual approach appropriate for ecosystem accounting, application for different purposes, and comparison across different characteristics, ecosystem types and countries;

(vii) Assessing the potential to aggregate across ecosystem assets and ecosystem types, and providing summaries across an ecosystem accounting area;

(viii) Defining links between ecosystem condition and ecosystem capacity to supply ecosystem services.

This Discussion Paper is intended to inform revision of the conceptual framework for ecosystem accounting and address the specific issues raised concerning implementation of ecosystem condition accounts. The objective of this discussion paper is to develop a framework for an inclusive account of ecosystem condition derived from an ecological understanding of the ecosystem within the accounting framework, upon which definitions, concepts and classifications are based. An inclusive framework encompasses the perspectives of different users and allows for different outputs to be produced for different purposes.

This paper is structured to provide a background of the current state of knowledge in terms of the definition and role of ecosystem condition in the accounting framework (section 2), to describe the new conceptual understanding of a multi-purpose approach to ecosystem condition accounting, including the components as inputs to and outputs from the accounts (section 3), applications of the accounts (section 4), the challenges for continued development of accounts (section 5), and recommendations for the revision process (section 6).

2. Background

Key concepts and components of ecosystem condition accounts are outlined as they are described currently in the SEEA documentation and scientific literature.

2.1 Definition of ecosystem condition

Ecosystem condition is described in the SEEA EEA (United Nations, 2012) as a characteristic of ecosystem assets, together with ecosystem extent. Condition is "*the overall quality of an ecosystem asset, in terms of its characteristics",* such as water, soil, carbon, vegetation and biodiversity (SEEA EEA 2.35, 2.36). Ecosystems are defined as "*dynamic complexes of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*" (SEEA EEA 1.52). Metrics describing ecosystem condition are selected appropriate to the characteristics of ecosystem types.

Ecosystem assets are measured from two perspectives; first, the characteristic of the asset in terms of ecosystem extent and condition, and second, the use of the asset in terms of ecosystem services (SEEA EEA 2.31). In a national accounting context, ecosystem assets and services need to be differentiated, the benefits to economic and other activities defined, and assigned to different beneficiaries. It is recognized that the relationship between ecosystem characteristics and their capacity to supply services, as well as the impact of human activities on ecosystem condition, may be non-linear and variable over time, and also vary depending on the service under assessment.

The definition of ecosystem condition in the SEEA EEA Glossary is "*the overall quality of an ecosystem asset in terms of its characteristics. Measures of ecosystem condition are generally combined with measures of ecosystem extent to provide an overall measure of the state of an ecosystem asset. Since ecosystem condition also underpins the capacity of an ecosystem asset to generate ecosystem services, changes in ecosystem condition will impact on expected ecosystem service flow."*

This definition is expanded by Bordt (2015), where ecosystem condition is represented by both quality measures and biophysical state measures that reflect the functioning and integrity of the ecosystem. The quality measures are usually levels that are assessed as having a positive or negative influence on capacity to provide ecosystem services. The biophysical measures set the context for these quality measures such as ancillary data and setting limits of states.

A need for different types of measurements of ecosystem condition was recognized in the Technical Recommendations, where both top-down and bottom-up approaches are suggested for measurements across different scales, and to differentiate fixed characteristics from variable characteristics. A continuum is described from the definition of indicators for individual characteristics for a single ecosystem type, up to the potential to define aggregated indicators that are comparable across ecosystem types with multiple characteristics (TR 1.73).

In the current revision, an expanded definition of ecosystem condition is suggested as "*the quality of an ecosystem that may reflect multiple values, measured in terms of its abiotic and biotic characteristics across a range of temporal and spatial scales*".

2.2 Role of ecosystem condition accounts within the ecosystem accounting framework

Ecosystem assets are described by the extent or quantity and the condition or quality of their stocks, and the changes in these stocks over time due to natural causes or human activities. Ecosystem condition links the stocks in assets, and the changes in these stocks, to the flows of services derived from the assets. The position of the ecosystem condition account within the ecosystem accounting framework is described in the Technical Recommendations and a modified version is shown in Figure 1. Ecosystem condition is assessed in physical terms.

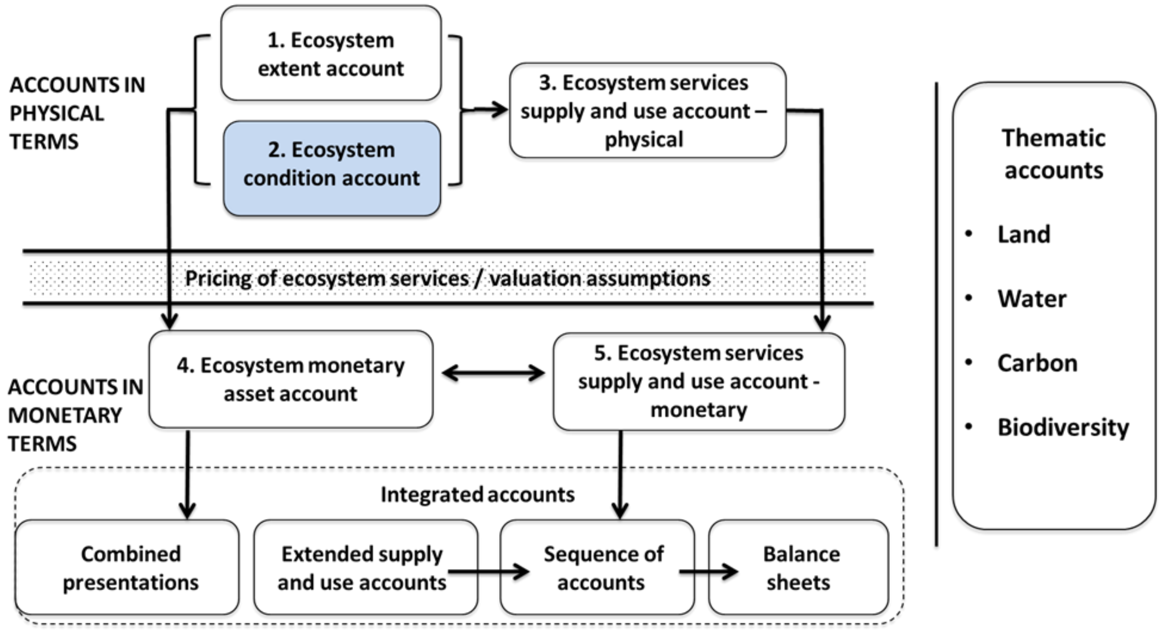

Figure 1. The position of ecosystem condition accounts within the ecosystem accounting framework. [modified from the Technical Recommendations by (i) not including Ecosystem Capacity which is not currently measured in terms of an account, and (ii) linking ecosystem extent and condition to the ecosystem monetary asset account]

An unresolved question in the ecosystem accounting framework is the link between the information in the thematic accounts (land, water, carbon and biodiversity) and the ecosystem extent, condition and service supply accounts. Much of the information reported in the thematic accounts is used in these three ecosystem accounts, for example as specific indicators of condition or services.

The role of ecosystem condition accounts is to integrate different sources of information that describe the characteristics of ecosystem assets. Often these data occur at different spatial and temporal scales that need harmonizing through interpolation or extrapolation, organizing into accounting tables, and presenting as maps, time series or other pertinent information. The ecosystem extent and condition accounts provide the basis of a common system of information about size, composition, state and types of ecosystem assets and their change over time.

Often data and information about ecosystem condition are collected as part of monitoring efforts aimed at informing management of ecosystems, but remains disparate and uncollated across and even within organizations. Ecosystem accounts can provide the impetus to harness such data and information and to increase its coherence and usability. The integrated nature of the accounts provides information in a more policy-relevant form than individual datasets from environmental monitoring.

Whereas most sections of the SEEA EEA framework are analogous with the sections of the more established System of National Accounts (SNA), ecosystem condition accounts are distinct in that no equivalent accounts exist in the SNA. In the SNA, all assets have an associated monetary value, which is established usually by market mechanisms. It is assumed that this monetary value already incorporates all relevant and known information about the condition of the SNA asset. Hence, the quality or condition of an asset is embedded in the measure of its quantity (or volume, in accounting terms). In ecological systems, there are no observable monetary values that describe assets, even if derived ecosystem services are produced and used by consumers.

The condition account demonstrates changes over time in the characteristics of each ecosystem type, and this can be used to measure past trends and current states. Information from the accounts can also be used to predict potential for change in the future. Ecosystem condition accounts can be used directly to address policy issues such as detecting degradation or improvement in the condition of ecosystem assets, or evaluating their state in relation to a baseline or towards a target. Changes in the condition of an ecosystem asset may also imply changes in its capacity to provide services, especially (but not only) if the condition indicators were selected from an instrumental perspective. Ultimately, condition accounts could be used to support estimates of the monetary values of ecosystem assets through the value of their expected future ecosystem service flows.

Defining ecosystem condition and selecting appropriate metrics is highly challenging as ecosystem condition is an inherently multidimensional concept, which is expected to capture a broad range of relevant ecosystem characteristics. A range of metrics, referring to any form of quantity that can be measured, are described in the components of ecosystem condition accounts (section 3.3). The guidelines for SEEA EEA could propose a structured list of possible characteristics, appropriate variables for measurement, and their associated indicators for each major ecosystem type, as well as a set of selection criteria. Metrics often need to be specific to ecosystem types and their characteristics. This combination of lists and criteria can offer a good combination of standardization and flexibility for specific accounts.

The ecosystem condition account should be compiled in biophysical terms that describe the characteristics of each ecosystem asset using a variety of measured variables and derived indicators. The accounting structure provides the basis for organizing the data, with ecosystem assets spatially aggregated to ecosystem types within the accounting area, and with distinct points in time as opening and closing of accounting periods.

The content of condition accounts will depend on the ecosystem types and their characteristics, data availability (current and potential), uses of the accounts and policy applications. Ecosystem condition accounts are usually compiled by ecosystem type within the ecosystem accounting area because each ecosystem type has distinct characteristics and thus a different set of variables and indicators.

Applying a generic assessment of ecosystem condition across an accounting area containing multiple ecosystem types also requires aggregation, where the different indicators describing a specific ecosystem type, or the different ecosystem types that occur in the same region, are aggregated into a smaller number of 'headline' indicators.

3. Progress towards an inclusive ecosystem condition account

This section describes the progress in understanding the conceptual basis for ecosystem condition accounting, introduces a proposed values framework that provides for an inclusive ecosystem condition account, and sets out the key components that are inputs to the ecosystem condition account and the outputs from the accounts.

3.1 Conceptual basis for ecosystem condition

In this paper, the definition of ecosystem condition is considered more broadly than previously. 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. Measured indicators are selected in relation to the purpose of assessment, and thus will vary in natural and human-modified ecosystems. Individual indicators can be aggregated to broader indices that provide a synthesis of the integrity, health or naturalness of the ecosystem asset. This flexible definition of ecosystem condition allows the information to be used for a greater range of purposes.

Ecosystem assets are multi-functional, adaptable and resilient, but also 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. Benefits to humans are derived from combinations of multiple ecosystem assets, hence relationships between condition of assets and benefits are complex, multi-dimensional, multi-scale and non-linear. Relationships between assets and flows of ecosystem services are similarly complex (Mace 2019).

Several long-standing integrative 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, can be seen as 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 Paris Agreement (UNFCCC 2015). A key aspect of these concepts is that they encompass both ecosystem conservation issues and the sustainable use of ecosystem services by humans. The broad overlap between terms is outlined in Box 1.

Box 1. Relationships between ecosystem condition and other related terms

Ecosystem condition is related to several other terms, and their different uses can be historical or disciplinary. For example, the term ecosystem health is often used by freshwater ecologists and the term naturalness is used by terrestrial ecologists.

Ecosystem integrity: Ecological integrity refers to maintaining the diversity and quality of ecosystems and enhancing their capacity to adapt to change and provide for the needs of future generations (IUCN 2019). Ecosystem integrity is defined as the continuity and full character of a complex system, including its ability to perform all the essential functions throughout its geographic setting; the integrity concept within a managed system implies maintaining key components and processes throughout time (IUCN 2019). It is described further as the system's capacity to maintain composition, structure, autonomous functioning and self-organisation using processes and elements characteristic for its ecoregion, and within a natural range of variability with little or no human influence (Dorren et al., 2004; Potschin-Young et al. 2018). 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 management target. Combinations of biological, physical and chemical indicators are used, and often in a manner to describe functioning as a self-organised system over time that is capable of resisting external pressures (Schaeffer et al., 1988, Rapport, 1989; Palmer and Febria 2012, 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).

Ecosystem International Union for Conservation of Nature Red List of Ecosystems: The 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)

In developing SEEA ecosystem accounting into an international standard with the aim of extensive application for informing environmental, social and economic policy, it is important that people from a broad range of disciplines accept, contribute to and use the system. This includes building upon the large amount of previous and current research on the concepts, objectives, data and interpretation from environmental sciences. A broad framework for ecosystem condition accounts with transparent value choices, clear concepts and a logical structure will encompass the range of disciplines and purposes in the use of the accounts.

3.2 Multi-purpose approach to ecosystem condition accounting

The definition of ecosystem condition and its implementation within accounting need to consider the purpose and the context of the application of the accounts. The aim is to identify what elements need to be included within the scope of ecosystem condition accounting to meet the objectives of ecosystem accounting related to linking ecosystems to economic and other human activities. Starting from the perspective of ecosystems, their extent and condition, the interdependency of all elements of ecosystem composition, structure and function contribute to maintaining ecosystem integrity, and hence the life-support system of the planet upon which humans depend. All these elements can be included in the accounting framework, but specific elements are selected depending on the purpose of the accounts and the nature of links between condition, services and benefits. Starting from the perspective of human benefits, specific ecosystem services are identified and linked back to the required ecosystem condition to supply the services. However, this perspective may not encompass all the characteristics of ecosystems that interact to provide the services. A broad and inclusive approach that enables a range of information to be included in ecosystem accounts will encourage convergence of these perspectives for specific examples of ecosystem condition and provision of services.

A spectrum of purposes for ecosystem condition accounts is considered in this discussion paper, which can result in the use of different variables and different outcomes and interpretations. The various types of purposes are described within a values framework represented by continua in two dimensions from intrinsic to instrumental values and from anthropocentric (centering on human beings) to ecocentric (centering on environmental conservation) worldviews (Figure 2) (adapted from the concepts in Turner 2001 and incorporating concepts from IPBES 2019). The reason for describing the multi-purpose approach in terms of a two-dimensional space is to illustrate that there are different types of factors that determine where a 'purpose' lies within this space. Different 'values', ranging from intrinsic to instrumental, can be defined in terms of reasonably specific purposes. 'Values' are also defined in the context of 'worldviews' that are more general concepts or perspectives about preferences for a particular state of the world, and here are defined as ranging from ecocentric to anthropocentric. Illustrating this values framework in terms of axes in two dimensions does not imply that the 'values' and 'worldviews' are linear or independent. The values framework can be collapsed to one dimension in cases where it is not appropriate to use the quadrants, for example, where different world views are not discernible.

The multi-purpose approach to ecosystem condition accounting encompasses values for a range of purposes that go beyond monetary values but are crucial for decision-making. A key tenet of the SEEA is the importance of combined presentation of physical and monetary metrics, which may be used independently. Different values, and their metrics, are used for different applications of accounts, for example, quantified relative comparisons or trade-offs need common metrics, whereas a management tool can use different metrics. Not all values can be incorporated into all components of ecosystem accounting, for example, intrinsic values may be difficult to quantify in an ecosystem service use account, and some monetary values may be difficult to express as exchange values. The term ‘values’ in the context of this values framework is distinct from the term ‘valuation’ that is often applied to a monetary value. Where there is likely to be confusion in the use of terms, specific definitions are recommended, for example ‘intrinsic-value’, ‘economic-value’.

Accounts developed for different purposes will respond to the needs of different audiences and users. This value framework is useful to understand the different perspectives or opinions people have about ecosystem condition as well as the different terms that have been used in the literature to define, communicate, indicate, measure or assess the quality of an ecosystem. Specifying the purpose of ecosystem condition accounts within this values framework will aid the selection and classification of indicators, and ultimately the effective application of the accounts. The different purposes encompassed by the framework, and the consequential metrics selected, represent gradations and are not necessarily mutually exclusive, as discussed in more detail below.

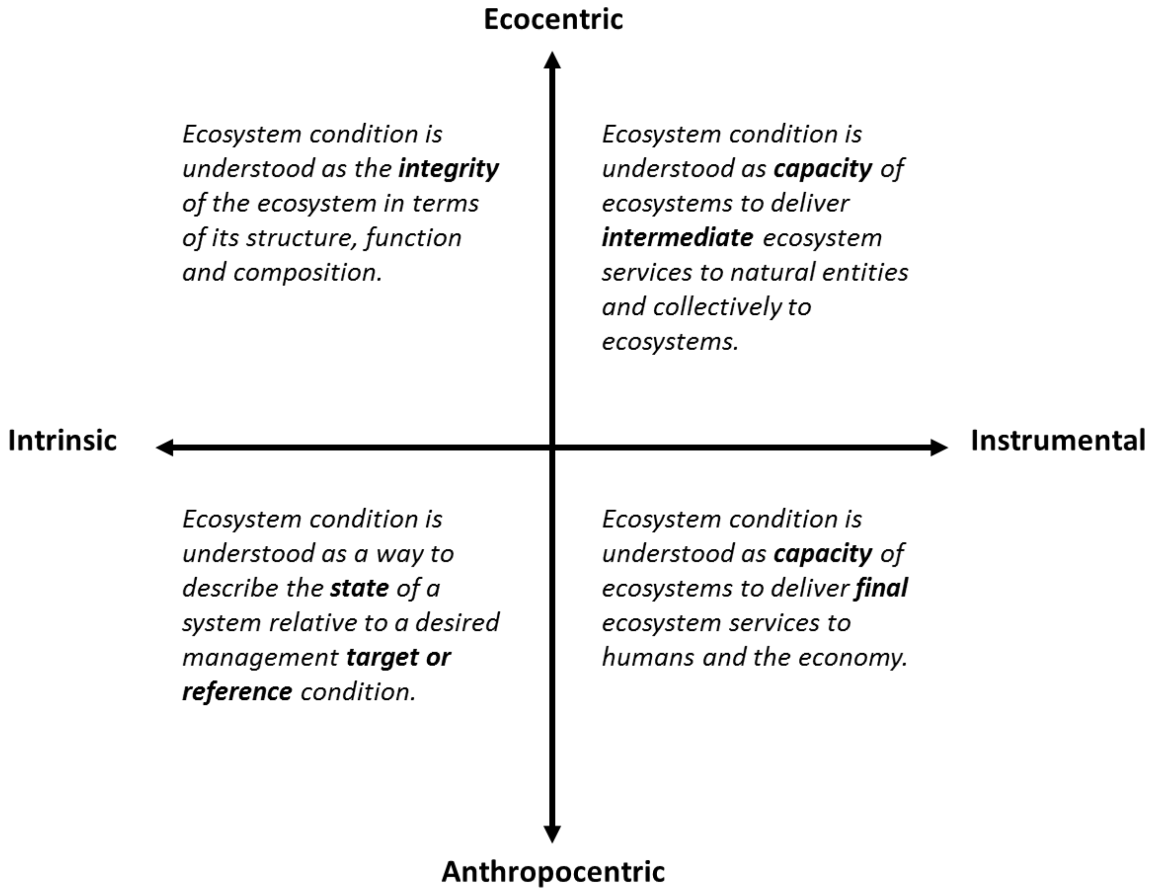

Figure 2 A general values framework in two dimensions representing the range from intrinsic to instrumental values and from ecocentric to anthropogenic world views (adapted from Turner, 2001)

The current description of the SEEA EEA is positioned mainly in the lower right quadrant of Figure 1 because the aim is to account for human uses of ecosystems and their contribution to the economy. When ecosystem condition is defined as the capacity to deliver final ecosystem services, this is an anthropocentric / instrumental category. Illustrating the purpose of ecosystem condition accounts in this two-dimensional framework demonstrates that a greater range of purposes exist, and hence types and applications of accounts.

The following describes the full suite of the axes of the values framework.

(i) Intrinsic values - the value of something is independent of any interests attached to it by an observer or potential user (Potschin-Young et al. 2018). Intrinsic values include:
   - Existence value of conserving ecosystem assets in their own right, independent of human interests. This can also be described in terms of naturalness or health.
   - Ecological value derived from system characteristics of the structure, function and composition of the ecosystem as a whole. Thus, the total value of the ecosystem exceeds the sum of the values of the individual functions. This can also be described in terms of ecosystem integrity.
   - Insurance value derived from the redundancy and ecological adaptive capacity allowing the ecosystem to sustain itself into the future under natural ecological processes, which can be

used to assess the potential to regain a natural condition. This can also be described in terms of resilience.

(ii) Instrumental values - the value that something contributes to a "means to an end" (Potschin-Young et al. 2018). Instrumental values include:

- Direct and indirect use values of goods and services provided by ecosystem assets for human use.
- Non-use values, which include altruism values to provide resources for others, and bequest values to provide inter-generational options and opportunities for the use of ecosystem assets in the future.

(iii) Anthropocentric worldview – interpretation of the world in terms of human values and experiences. Humans ascribe values to ecosystem goods and services, but they may be use or non-use values to humans.

(iv) Ecocentric worldview – interpretation of the world in terms of all living things in nature. Values ascribed to ecosystem goods and services that are independent of human interests.

The intersections of the values framework and their contribution to different purposes of ecosystem accounts are described by the following:

- The ecocentric / intrinsic category includes maintaining the on-going functioning of the ecosystem without reference to humans.
- The ecocentric / instrumental category includes intermediate ecosystem services that reflect dependencies among ecosystem types and independent of human interests. Intermediate ecosystem services are also referred to as intra- and inter-ecosystem flows or supporting ecosystem services.
- The anthropogenic / intrinsic category includes the philosophical position of actions for environmental protection for the collective good rather than services for specific beneficiaries (for example, Singer 2010), but still has a human value ascribing intrinsic values.
- The anthropocentric / instrumental category is related to the capacity to supply a flow of ecosystem services for human beneficiaries.

This multi-purpose approach to ecosystem condition accounting is consistent with that used in the Global Assessment on Biodiversity and Ecosystem Services (IPBES 2019) described as multiple values in decision-making. IPBES includes an additional category along the spectrum - relational values, which are values derived from the relations between humans and with nature, and the meaningfulness of relationships, but not necessarily their use. Additionally, along the spectrum of worldviews there is a perspective of oneness between nature and humans that is often associated with indigenous peoples.

Accounts derived under this spectrum of values can have different applications, either directly related to the values of the original purpose of the accounts and the consequential indicators selected, or to broader purposes for which the indicators are relevant. Thus, ecosystem condition accounts have a high degree of flexibility in terms of application to policy questions and management challenges. The following list of applications represents an increasing order from intrinsic to instrumental values.

- Describing condition with characteristics related to natural or target levels associated with levels of structure, function and composition. This perspective may take an historical view with a comparison of a current state with an initial, natural or undisturbed state from the past, or use comparisons across different locations.
- Identifying changes in ecosystems as declining condition or degrading, linking to concepts of human impact.
- Assessing progress towards targets for environmental restoration, quality or conservation from an ecological perspective, which emphasizes the scientific measurement of ecological integrity.
- Describing condition with characteristics necessary for supplying ecosystem services, in relation to the future and the potential flow of services with reference to the benefits for human well-being.
- Identifying changes in ecosystems as improving or degrading in terms of their capacity to supply ecosystem services.
- Assessing progress towards targets for environmental restoration, quality or conservation from a socio-economic perspective, which conforms to the logic of socio-economic decisions (for example, where to prioritize restoration actions to improve degraded land).

The aim of this values framework is to be broad rather than prescriptive, and to support the appeal for convergence in the work of different disciplines and perspectives (Saner and Bordt 2016). They suggest that convergence can be facilitated by adopting broad values, long timeframes and the precautionary principle, and identifying critical natural capital. The intrinsic values associated with non-human nature may not fit well in the ecosystem services paradigm of benefits for humans, but are important to include within the framework as this underlies many of the objectives in application to conservation (Batavia and Nelson 2017).

Underlying individual preferences for ecosystem goods and services often are not all well-defined, but fit within this two-dimensional framework. The range of purposes described for condition accounts may or may not produce similar results about the relative state of an ecosystem and the identification of beneficiaries. Assessment of the relative condition of an ecosystem may differ depending on the perspective of intrinsic or instrumental values, that is, the value of ecosystems in their own right or their value to supply ecosystem services. In many cases, accounts derived for different purposes resolve to a quite similar general understanding of what constitutes good condition for an ecosystem, because; (1) in many ecosystems, characteristics that drive supply of ecosystem services are largely the same that confer ecological integrity, and (2) on a practical level, data availability often confines choices to the same limited set of indicators.

An example where different positions within the values framework use similar indicators (and underlying data) is where condition accounts for native grassland are inferred from the richness, composition and abundance of its wild bee community. The bee population has an ecocentric / intrinsic value contributing to the biodiversity and functioning of the ecosystem. The condition of the bee population can also be used to measure the capacity of the grassland to deliver pollination services, where pollination of wild flowers is an intermediate service that maintains the habitat and lies in the ecocentric / instrumental category. The pollination of crops in adjacent farmland contributes to a final service that benefits farmers and lies in the anthropocentric / instrumental category. Hence, data about the bee population can be used as indicators for different purposes, but the outcomes may be interpreted in different ways.

An example where the same characteristic is measured, but using different indicators for different purposes in the values framework, is that of native forests. Forests have an ecocentric / intrinsic value because many consist of trees that are hundreds or thousands of years old, being some of the oldest organisms on Earth. Forests sequester carbon dioxide from the atmosphere and this can be measured by the accumulation of biomass. This process contributes to climate change mitigation and thus has an intrinsic / anthropogenic value. Trees provide habitat for other organisms, such as epiphytic plants and hollow-nesting birds and animals, thus promoting biodiversity and ecosystem functioning, and so have an ecocentric / instrumental value. Native forests provide many goods and services for indigenous people, such as fruit, medicinal plants, firewood, cultural and spiritual services, and so have an anthropogenic / instrumental value.

An example where the same variable may be measured to quantify ecosystem condition for different purposes is that of forest age. From an ecocentric / intrinsic value for ecosystem integrity and an ecocentric / instrumental value for habitat provisioning, ecosystem condition increases with increasing forest age towards a reference level of old-growth or primary forest. From an anthropogenic / instrumental value, the supply of the ecosystem service of timber provisioning increases with forest age up to an optimum age for harvesting, and then declines in older forests.

In practice, it is far from easy to draw clear boundaries of where use or non-use values end or where different worldviews start. People and policies use multiple values, sometimes simultaneously, without attempting to unravel them or to plot them on the two dimensions of the figure. All measurements serve a certain purpose and whatever is measured affects the outcome and interpretation.

Intrinsic arguments, non-use values and non-anthropocentric worldviews have been used in contributing to environmental policies. Consequently, several frameworks of indicators have been developed to measure ecosystem integrity and this information can be applied to ecosystem condition in the context of the SEEA EEA (referred to in DP2.3). The two-dimensional values framework attempts to place in context the existing ecological knowledge and methodologies with the instrumental approach

Incorporating multiple values into ecosystem accounting promotes the concept of benefits to humans, which is interpreted as the maintenance of ecological processes that provide the life-support system of the planet. Components of this life-support system are recognized in the classification of ecosystem services in the Millennium Ecosystem Assessment, which includes supporting services, regulating services, cultural services as well as provisioning services (MEA 2005), and in international conventions such as UN Framework Convention on Climate Change, Convention on Biological Diversity, UN Convention on Combating Desertification.

In conclusion, the purpose of ecosystem accounts is to provide information in a standardized system for a wide range of applications and at a range of scales. Hence, the interpretation of terms such as ecosystem condition should be as broad as possible to accommodate the range of current and potential applications. This discussion demonstrates that condition accounts can serve multiple purposes and can profit from an already well-developed knowledge base of concepts, indicators, and measurements. This aspect has so far not been addressed by the SEEA EEA and could be developed further in the SEEA EEA revision.

3.3 Components of ecosystem condition accounts

3.3.1 Framework

The proposed approach to assessing ecosystem condition allows for a multi-functional use of the accounts. To accommodate the different perspectives and values that can be used to frame ecosystem condition, we introduce a series of metrics to describe condition and its links to other sections of ecosystem accounting (Figure 2). Metrics is a general term used to describe all quantitative measures of the characteristics of the system, and are sub-divided according to the purpose of the measurement and named as different components (variables, indicators and indices).

Applying the metric of 'variables' to ecosystem condition accounting provides a means of presenting information that can then be used for different purposes (see DP 2.3 on the typology and criteria for ecosystem condition variables). Definition and selection of variables conform to a consistent framework of criteria whilst also being appropriate for the ecosystem type. An ecosystem condition account can be composed of each of the following components, either individually but ideally including all the components. The first stage is to identify the most relevant *ecosystem characteristics,* and the second stage is to identify the appropriate *variables* and *indicators* as quantitative measures of each of the characteristics.

(i) ***Ecosystem characteristics*** describe the system properties of the ecosystem in the categories of vegetation, water, soil, biomass, habitat and biodiversity, with examples of characteristics including vegetation type, water quality and soil type. Characteristics relate to the operation of the ecosystem and its location (SEEA EEA Glossary, Bordt 2015), with the operation in terms of composition, structure, processes, function, and location in terms of extent, configuration, landscape forms, climate and associated seasonal patterns.

(ii) ***Selection criteria*** can be considered as a tool to identify the relevant pieces of information among the many characteristics, variables and indicators that could be considered in a flexible yet standardized way. There are two major steps where selection criteria make sense: a more conceptual selection can be made across the various ecosystem characteristics, and a more pragmatic selection can be made at the level of variables and indicators. Selection criteria are discussed in detail in DP 2.3.

(iii) ***Ecosystem variables*** are measurable quantities describing characteristics of an ecosystem that may be physical, chemical or biological. Examples of variables associated with the above characteristics are slope (degrees), temperature (degrees Celsius), soil texture class, tree coverage (%) and turbidity (nephelometric turbidity unit NTU). Variables differ from characteristics (even if the same descriptor is applied to them) as they have units to indicate what quantity or quality they measure.

Variables measure individual characteristics. A single characteristic can have several associated variables, which can be complementary or overlapping with each other. Variables that are sensitive to change and can be used to monitor and report changes in the state of ecosystem assets can be included within an ecosystem condition account.

Measurement of soil pH is an example of a variable that is sensitive to change due to human land management and monitoring this change, irrespective of a reference level, is useful to report in a condition account to demonstrate changes in soil properties due to human impacts or changing environmental factors. A change is reported but not assessed as being good or bad in itself.

(iv) ***Ancillary data*** refer to variables that describe stable environmental characteristics and are unlikely to change due to human activities, for example elevation or slope, and so are not included in a condition account but used as ancillary data (see Figure 2 and criteria in discussion paper 2.3).

(v) ***Reference level*** is the value of a variable at the reference condition and against which it is meaningful to compare past, present or future measured values of the variable in order to derive an individual indicator.

(vi) ***Target level*** is the value of a variable at a desired state or temporal baseline against which it is meaningful to compare past, present or future measured values of the variable in order to derive an individual indicator. This metric represents a defined condition that can be used as a baseline.

(vii) ***Ecosystem indicators*** are derived when variables are set against reference levels. An indicator includes the values and comparisons with relevant reference levels. An indicator is used to assess an aspect of ecosystem condition with a view to informing policy and decisions. Indicators usually have the same descriptor as the variable. Different indicators for the same ecosystem type may have different scales and different measurement units. Variables used to derive indicators are those that are likely to change because of human interventions (see criteria in discussion paper 2.3), for example, tree coverage and turbidity are likely to change and hence be relevant to policy.

Examples of indicators based on the above variables include changes in tree cover or number of species from a ‘natural’ state or since a point in time, or evaluating nitrogen concentration or turbidity in water in relation to a prescribed threshold value considered as harmful.

From the example of measuring soil pH, when appropriate reference levels are applied, for example optimal pH for different crops (from an instrumental perspective), or pH in an unmodified state (from an intrinsic perspective), then an indicator can be derived that assesses relative benefit for each crop, or the degree of modification from a reference condition of “natural”.

(viii) ***Ecosystem service capacity*** is derived from variables or indicators of ecosystem condition that are compared with a sustainability threshold to infer the capacity of ecosystems to provide ecosystem services in a sustainable way. The relationship between ecosystem condition indicators and the supply of ecosystem services is not necessarily a direct one, and may be curvilinear (non-monotonic) or even negative. To estimate the capacity of an ecosystem to supply a specific service, various combinations of ecosystem variables are needed. Not all variables contribute to ecosystem services, but a set of variables is selected that contributes to defining the capacity to deliver a specific service, and this set of variables will differ depending on the service.

For example, slope and tree coverage are two variables essential to measure the capacity of forests to prevent rock fall, landslides or avalanches from impacting downhill villages in the mountains. Tree cover is an ecosystem variable that can be used both as an indicator in the condition account as well as a determinant for capacity. Slope, however, is an ecosystem variable that is not used to assess ecosystem condition, but is important to define capacity. Therefore, it is considered as an ancillary data source to assess capacity.

(ix) *A* ***typology of ecosystem condition*** is a comprehensive hierarchical classification (proposed typology of ecosystem condition – see DP 2.3) for ecosystem condition metrics that can create a meaningful reporting and aggregation structure. There are many ways to group the potential indicators for ecosystem condition. The typology defines broad classes of data types. Relevant metrics are identified within each of these classes. Once a typology is determined, a set of metrics means that per class/type there is at least one measurement. Levels in the hierarchy of condition metrics are aligned with different purposes.

(x) *An* ***aggregate sub-index*** is derived from a combination of indicators that describe a single characteristic of the ecosystem type. Combinations of indicators are usually those that show change in ecosystem condition in the same direction. Component indicators (sub-indicators) are assessed in terms of a common standard, weighted appropriately and combined to form a composite. Specific reference levels can be applied in the aggregation to derive sub-indices.

(xi) *An* ***aggregate index*** condenses all characteristics into a single indicator for an ecosystem type, or one characteristic across ecosystem types, where all types are compared to a single reference condition. A typology for indicators and an aggregation scheme are used to help aggregate different indicators or sub-indices. Where an aggregate index is used to assess ecological condition, the input indicators and their assigned reference levels must be stated explicitly.

(xii) ***Reference condition*** is a point against which to compare past, present and future ecosystem condition for use as a standard. Comparison is usually across ecosystem types or classes of characteristics, and in relation to spatial units within ecosystem accounts. The reference condition is described by the aggregated values of the set of indicators within ecosystem types or classes at their reference levels. Reference condition refers to a natural state, or integrity of the ecosystem, that is represented by intact ecosystem processes including food chains, species populations, nutrient and hydrological cycles, operating under natural dynamics. The metric of condition represents the distance from natural irrespective of the characteristic or ecosystem

type. Reference conditions are used for estimation and comparison, and do not imply a policy goal or a desired condition.

If a natural state is not possible to use as a reference, particularly in relation to various long-term land uses, then alternative stable ecological conditions can be considered but must be stated explicitly.

According to this framework, accounts should be developed in practice by starting with the variables selected within each class of the typology according to selection criteria. Then different combinations of these variables in association with reference levels are used to derive indicators of condition. Some ecosystem condition indicators, in various combinations, are appropriate to combine with ancillary data to derive indicators of the capacity to provide ecosystem services.

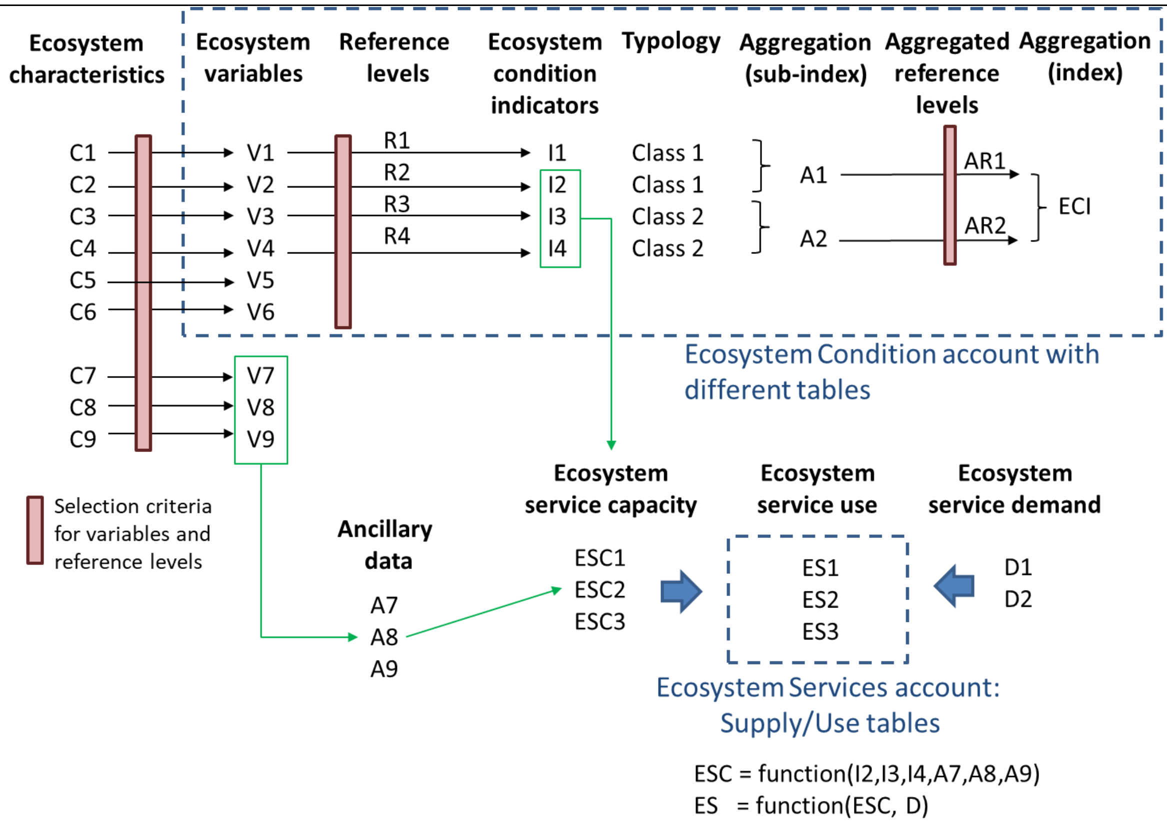

Figure 3. Components of an ecosystem condition account and relation with the ecosystem service account. The scheme starts with 9 ecosystem characteristics (C1, C2, …, C9). Ecosystem characteristics can be quantitatively measured by ecosystem variables (V1, V2, …, V9). In this scheme, for every ecosystem characteristic there is one variable selected for measurement that passed the selection criteria. This is indicated by the arrows between characteristics and variables. There are two groups of variables. Measurements of the variables V1, V2, …, V6 are included in the condition account, and describe the condition of ecosystems, for instance the presence of a keystone species, the concentration of nitrogen, or the percentage of organic carbon in soil. Variables V7, V8, and V9 describe an ecosystem characteristic but they cannot be used to measure condition, for instance the slope of the terrain, and so are not included in the condition account. Particular reference levels can be assigned to variables V1, V2, V3 and V4 , respectively R1, R2, R3 and R4. When a measure of a variable is related to a reference level, it can be used as an indicator, shown as I1, I2, I3 and I4. Variables V5 and V6 do not have assigned reference levels, and so do not have indicator status, but can show trends over time in the variable. Every indicator can be classified using a typology or classification system. Here we assume that I1 and I2 are class 1 indicators whereas I3 and I4 are class 2 indicators. These classes can be used to aggregate indicators. I1 and I2 have been aggregated into sub-index A1, while I3 and I4 have been aggregated into sub-index A2. Sub-indices can be related to aggregated reference levels (AR1 and AR2) in a normalization process that allows comparison across aggregated indices. Then a second aggregation step delivers ultimately ECI, an ecological condition index. The scheme also explains how the condition account, together with ancillary data, can be used to calculate or assess ecosystem service capacity. Several condition indicators, in this case I2, I3 and I4, are used to assess the capacity (or potential) of ecosystems to produce particular ecosystem services. This assessment also relies on ancillary data (A7, A8, A9) which are in essence ecosystem variables not included in the condition account.

Consider pollination. The capacity of an ecosystem to provide pollination services will depend on pollinator species abundance and temperature (if too cold, pollinators will not fly out). Species abundance can be used as an indicator in the condition account to assess the condition of ecosystems; temperature is usually not suited as a condition indicator but considered here as ancillary data, necessary to map or quantify capacity. ESC1, ESC2, and ESC3 are three quantities that express the capacity to deliver ecosystem services ES1, ES2, and ES3, respectively. Finally, ecosystem services are actually used when this capacity is satisfying a certain demand, here expressed by D1 and D2. Not all ecosystem services have a conscious demand, for example air filtration services, and so a demand has not been shown for every ecosystem service.

3.3.2 Reference condition and reference levels

Ecosystem condition is assessed in terms of change in measured indicators over time that are compared with an associated reference level. Change in aggregate indices comparing ecosystem types is determined in relation to a common reference condition. Ecosystem condition accounts need to provide information to show:

(i) total gains and losses compared with a reference or baseline, which represents the potential ecosystem type and condition, and records historical losses;

(ii) annual gains and losses as a time series, which is compared against a reference condition appropriate for the extant ecosystem type and that show change on a meaningful scale.

Depending on the response function of the indicator, comparison of states of condition on a normalized scale, for example from 0 to 1, may need to have reference levels or reference conditions at both ends of this scale.

A **reference condition** essentially sets the scaling used for comparison of ecosystem condition indicators allowing conversion of metrics to a common scale (such as, between 0 and 1), which can then be used in aggregation. The reference condition represents the opening stock in a condition account, and the value of the condition indicator measured in the first year defines the change from the reference condition. The time series of changes in the condition indicator in subsequent years may be reported on a different scale if their magnitude is very different to the initial change from the reference condition. The reference condition is a point against which to compare past, present or future condition, but does not imply a policy goal, target or desired state.

The reference condition represents the condition of an ecosystem to maintain ecological integrity. It is best used to refer to the natural state, which is a neutral concept. The reference condition of an ecosystem corresponds to the condition where the structure, composition and function are dominated by natural ecological and evolutionary processes, incorporating self-regeneration, and involving dynamic equilibria in response to natural disturbance regimes. An ecosystem in its reference condition attains maximum ecological stability (Gibbons et al. 2008, Palmer and Febria 2012, Mackey et al. 2015).

Using the natural state as the reference condition allows recognition, and therefore the benefit, of the natural state and change from the natural state to be incorporated into ecosystem accounts. The natural state may not be related to supply of direct ecosystem services or be the management goal for changing the current condition of an ecosystem. However, recognition of the change from the natural state is important for assessing conservation values.

Ecosystem accounts are developed by different organisations and for different purposes. It is important that the definitions and framework allow accounts to be developed devoid of value judgements, for example to meet the standards of national statistics offices. In this case, setting target levels and defining anthropocentric-derived condition are not appropriate. Use of target levels may be appropriate for management tools where policy goals are stated explicitly, but may have limited application for comparison across regions or countries when based on different value systems and subject to human interpretation.

The term reference condition is 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 refer 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 term reserved for reference condition for ecological integrity (Stoddard et al. 2006).

In some cases, a reference condition as 'natural' does not represent a realistic state to define for current ecosystem types. In ecosystems where humans have been influencing the environment for thousands of years, the environment has changed due to both human and natural processes that often cannot be distinguished, and recent natural disturbances have changed landscapes during human history, it may not be possible to define a reference condition as 'natural' in absolute terms. Both the timespan and extent of human influence has varied in different parts of the world, hence assigning a date in time as the reference condition is problematic. For example, variation has occurred in the time of human settlement, development of agriculture, hunting, domestication of livestock, use of fire to influence vegetation structure and composition, major land clearing and intensive production. In ecosystems that have been modified extensively by human activities to provide ecosystem services, a natural state may not be the target state for an ecosystem to return from an anthropocentric perspective. In these cases, it may be more appropriate to use target levels as the baseline to assess indicators associated with an anthropocentric condition. Returning to the reference condition may not be possible because of climate change or irreversible changes due to human activities such as pollution, nutrient loads, erosion or vegetation clearing.

A range of options is necessary for assessing condition given the variation in the degree of modification of ecosystems by humans, and the different objectives for management or their target states. Using the reference condition as the natural state is preferred and recommended, even if it does not represent the target state. Assessment of the change from the reference condition allows greater understanding of ecosystem change and potential for restoration if desired, as well as an objective baseline for comparison. In addition to the reference condition, an anthropocentric-derived condition can be used as a baseline for comparisons but the derivation must be stated explicitly and preferably refer to a stable condition of the ecosystem. Options for establishing reference conditions and a gradation of anthropocentric-derived conditions are summarized in Table

1. Reference conditions, and their associated reference levels, can be difficult to determine appropriately and explicitly, and describing the rationale for their selection is important.

The method used for defining the reference condition must be appropriate for all realms: terrestrial, aquatic and marine. Although a global agreement on a reference condition would be useful for comparisons, for instance to evaluate individual country commitments for ecosystem restoration, it is likely that countries or regions prefer to benchmark ecosystems against a nationally or regionally agreed reference condition.

Reference levels are used to compare past, present or future measured values of a variable in order to derive an individual indicator. The reference level is the value of the variable at the reference condition of the natural state, and thus the metric represents the distance from the reference condition. Where an anthropocentric-derived condition is used for the comparison, a target level is defined for the value of the variable against which it is meaningful to compare past, present or future measured variables of condition.

A reference level can be set with different options for the magnitude depending on the purpose of the indicator for ecosystem condition, particularly differentiating between purposes for intrinsic or instrumental values. Hence, different indicators can be derived from the same variable when different reference levels are assigned. Defining the reference level is related to the values perspective and must be stated explicitly. Different reference levels can be applied to an indicator for different purposes, for example, the bee population for pollination of wildflowers requires species richness and abundance, but for pollination of crops may only require bee abundance because the range in species is not as important for individual crops. Additionally, reference levels applied to indicators are likely to differ for different ecosystem types, for example, using an indicator of biomass such as normalized difference vegetation index (NDVI), can be different for a forest, savannah and grassland. Reference levels are used in the normalization process necessary to generate aggregated indices of condition.

Based on the different options for establishing reference conditions, the individual reference levels applied to indicators can be assigned using different types of information, including: absolute values of the measurement, data from sites in a reference condition, models of ecosystem dynamics or species populations, expert assessment, maximum potential quality for the ecosystem type. Setting of reference levels associated with anthropocentric-derived conditions, such as target, prescribed or threshold values, requires expert opinion based on understanding of the ecosystem types, and therefore is preferably not used as a standard.

Reference levels can be set at upper and lower levels of the range of a condition variable. For example, the upper level may refer to a natural state and the lower level may refer to a degraded state where ecosystem processes are below a threshold for maintaining function.

The definition of reference conditions and setting of individual reference levels may be complicated due to changing global conditions, particularly climate change. Global change may make an objective of attaining a natural state no longer possible.

Table 1. Options for establishing reference conditions (1 – 3) and anthropocentric-derived conditions (4 - 8).

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.	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)	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.	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 Requires assumptions to establish reference levels for condition variables.	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 values of available data.	Relies on data for the range in values at the current state.	
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 (Setting a baseline year against which (past, present or future) condition can be evaluated)	Can be used to assess the condition of novel ecosystems or ecosystems heavily modified by humans Can be based on current data of ecological characteristics and maximum values or statistical approaches such as percentiles.	Reliance on contemporary data in evaluating changes can result in a shifting baseline. Appropriate dates differ for different indicators and ecosystem types. 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	1990 (Kyoto protocol for GHG emissions) 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.	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
7. Prescribed levels in terms of legislated quality measures or expert judgement	Provides a mechanism for enforcement	Can be subjective and influenced by policy	Pollution levels
8. 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

It is important that the methods recommended for ecosystem condition accounting, including establishing reference condition and the associated change in indicator values are suitable for supporting international conventions, and consistent with existing reporting guidelines. International conventions are increasingly adopting targets set against reference conditions. Where existing definitions of reference condition used in international conventions are appropriate and data are available, it is beneficial to adopt consistent methods.

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 differs between countries.

UNCCD United Nations Convention on Combatting Desertification

- The baseline for land degradation is the initial value of the indicators;
- Countries can set their own baseline;
- The target condition is the same as the reference condition. 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 they assess progress to 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)

3.3.3 Aggregation of indicators

The aim of aggregation is to generate a single or simplified index for a specific ecosystem asset. Aggregation of indicators can be done spatially, temporally or thematically. Spatial aggregation is done by ecosystem types within an ecosystem accounting area, and this is required for all forms of spatial reporting. Spatial configuration is important in the aggregation process, not just the sum of the ecosystem assets. Indicators of condition can emerge at larger scales such as landscapes and ecosystem function, for example fragmentation and catchment hydrology. Temporal aggregation can be done at different scales depending on the purpose and other information to which it is related, for example financial year economic data, or growing seasons for particular plants. Thematic aggregation combines different indicators describing groups of characteristics related to a theme within an ecosystem type, and should be based on the typology of ecosystem condition variables (DP 2.3).

Types of issues that require consideration in the process of thematic aggregation over various indicators and indicator classes in a single ecosystem asset / ecosystem type, include: (1) selection of indicators, (2) types of aggregation functions, (3) weighting, and (4) hierarchical approach.

Aggregations involving multiple ecosystem assets, for example spatial aggregations of a single indicator, or aggregating cross-cutting indicators across different ecosystem types, might involve other considerations such as weighting by the spatial area.

(1) **Selection of indicators** is critical and requires consideration of their relative importance in the context of the purpose of the condition account, and relationships between indicators including their potential auto-correlation. Indicators to be aggregated are assessed in terms of aggregated reference levels to provide a common standard, weighted and combined to form a composite or index. Aggregate indices are related to reference conditions for the ecosystem types in an accounting area. Some indicators are meaningful only when aggregated at larger scales, for example fragmentation, connectivity and some diversity indices.

(2) **Aggregation functions** are used to standardize the data and select a 'relative' basis from the data, which is used for linear transformation of the data to a 0 to 1 (or 0 to 100) range. Functions to calculate central tendency include:

a. Arithmetic mean (a generally used and easily understood central tendency with many advantageous mathematical properties),
b. Geometric or harmonic mean
c. Median, quantiles, minimum, maximum values (can provide robust alternatives to the arithmetic mean for specific purposes).

These simple statistical functions may be adequate to produce aggregates indices, but more complex weighting systems and ranking can be applied.

(3) **Selection of a weighting system** depends on the relative importance of each indicator to an assessed overall condition of the ecosystem. The approach to weighting should have a scientific rationale. Among methods of weighting for aggregation, equal weighting assumes commensurability and this is not necessarily true across indicators, reference levels or ecosystem types. Non-equal weighting may be appropriate if the different characteristics, measured by their respective indicators, play relatively different roles from an ecological perspective or in their potential supply of ecosystem services. Relationships between characteristics may be non-linear and different thresholds may apply.

An equal or differentially weighted arithmetic mean approach is the most common, but a range of other approaches such as geometric or harmonic means and maximum/minimum operator approaches are also used.

(i) Weighted arithmetic mean: $CI = \sum_{i=1}^{n} w_i q_i$, where $q_i$are the individual indicators used in the calculation of the overall condition indicator, normalized such that they are on a consistent scale, and $w_i$are their associated weights (subject to the condition that $\sum_{i=1}^{n} w_i = 1$). If all weights are equal to 1/n, this simplifies to the equally weighted mean $CI = \sum_{i=1}^{n}(q_i/\text{n})$.

(ii) Weighted geometric mean: $CI = \prod_{i=1}^{n} w_i q_i$.

(iii) Weighted harmonic mean: $CI = \sqrt{\frac{n}{\sum_{i=1}^{n} 1/q_i}}$.

The main advantage of the geometric mean over the arithmetic mean is that the geometric mean has more sensitivity to low values. For this reason, more generally in environmental science, the geometric mean is often used for describing statistics associated with variables that tend to vary in space or normalized indicators that vary by several orders of magnitude. The harmonic mean similarly is more sensitive to the lowest values of an indicator than the arithmetic mean, while still sensitive the higher values.

An example of weighted means for aggregation of indicators is that for water quality, where use of the geometric mean has been the preferred method. An index derived from the geometric mean of multiple single measures of water quality was found to be more than a factor of two closer to expert judgement of overall condition based on seeing those measures than the index derived from the arithmetic mean (Walsh and Wheeler 2012).

Another common approach to recognize the importance of the lowest values or most impaired condition of an indicator, or alternatively the highest values or best, most intact indicator, are minimum or maximum operator approaches.

(i) Minimum operator approach: $CI = \min(q_1, q_2, \dots q_n)$
(ii) Maximum operator approach: $CI = \max(q_1, q_2, \dots q_n)$.

In some cases, combinations of the minimum operator approach or threshold detection approach, along with weighted arithmetic, geometric or other mean approaches to the full set of indicators may be a useful. The minimum operator approach could be used to account for a subset of indicators where threshold effects are particularly important, and others could be weighted according to relative importance and averaged as appropriate.

Other approaches to weighting include preferential weighting, for example, based on expert judgement about relative importance of the indicators / indicator classes, but this should be well-justified and coordinated to ensure comparability. The one out - all out approach, where the condition index is based on the lowest value indicator, is a special case of using the 'minimum' function as the central tendency. Additionally, potential approaches that might be applicable to derive meaningful overall condition indicators are the use of statistical data mining techniques such as principal component analysis or hierarchical cluster analysis. These approaches require sufficient training data and expert knowledge are available, but can be useful to disentangle complex, interacting factors and thresholds underlying assessments of condition.

(4) An **hierarchical approach** to aggregation reflects the structure of an hierarchical indicator classification, such as the typology in DP 2.3, from the bottom to the top, that is, first aggregate sub-indices from the indicators, and then an index from the sub-indices. Hierarchical aggregation schemes should also contain instructions on how missing indicators / sub-indices should be handled. The hierarchical structure means that indices are scalable across spatial resolutions. Data for individual variables or indicators should be preserved is a disaggregated form and as high a resolution as possible within the information system. Aggregation is the last step in analysis and it should be possible to scale up and down and across at different resolutions depending the purpose and form of analysis.

A flat approach to aggregation does not consider the hierarchical structure, for example, a flat arithmetic mean with equal weighting would take the mean of all indicators at once. This approach is biased towards indicator classes with more indicators.

Methods for weighting and normalizing scores can be complex and influence the outputs, so explanation of the assumptions is important. Assessment of the applicability of aggregated indices across characteristics or ecosystem types should be tested. In addition, selection of methods for aggregation of condition metrics derived for individual spatial units should consider the landscape context and derivation of representative mean and range in condition. The typology for classification of indicators provides a basis for this aggregation process.

3.3.4 Relationship between ecosystem condition, ecosystem service capacity and supply of ecosystem services

In the SEEA EEA conceptual framework, ecosystem capacity does not belong to the ecosystem condition account (SEEA EEA 4.24, TR 1.3.6). Details of the methods and requirements related to capacity are discussed in other documents of the SEEA EEA revision process. Ecosystem service capacity is closely associated with ecosystem condition when the purpose is based on instrumental values, and as shown in Figure 2. The concepts and practical accounting for condition, capacity and services can be distinguished and maintain internal consistency of the whole SEEA EEA accounting framework (La Notte et al. 2019a). Extending the production boundary to include potential as well as actual flows of ecosystem services allows assessment of sustainable use of ecosystem services (La Notte et al. 2019b).

Similar variables can be used to quantify ecosystem condition, capacity and flows of ecosystem services. A key difference between condition indicators and ecosystem service capacity indicators derives from the purpose for which they are developed: ecosystem service capacity indicators are strongly (and exclusively) linked to a single specific ecosystem service, whereas condition indicators are (potentially) associated with multiple services. Further distinctions between indicators for condition and specific services are discussed in DP 2.3. In order to avoid confusing overlaps between the different sections of the SEEA EEA accounting framework, good practice would distinguish clearly the indicators in the condition, capacity and service accounts.

Multiple characteristics can influence the capacity of a specific ecosystem type to supply a specific ecosystem service [TR 4.69]. The same characteristic can influence different services in different ways. The most relevant characteristics can (and should) be covered by the ecosystem condition indicators in the condition account. The relationships between the condition indicators and the services can be weak or strong, linear or complex. The condition account thus provides physical metrics as variables or indicators to be used in their own right (typically measured in units specific to the ecosystem types and their characteristics), which should be detached from the ecosystem service indicators (directly measuring a single specific service, typically in units specific to that service). Nevertheless, condition indicators can be linked to various services, and in some cases, they can even be used as direct input data for ecosystem service capacity models.

Ecosystem condition should be more general and integrative than the capacity to supply specific ecosystem services. Characteristics of ecosystem condition, and their associated measured variables and indicators, should include more than those restricted to providing final ecosystem services used by humans. This should include indicators of intrinsic values of condition and the provision of intermediate ecosystem services, such as habitat.

3.4. Typology of ecosystem condition

3.4.1 Proposed typology

Classification has been based on the proposed broad and inclusive framework of ecosystem condition with the spectrum of purposes from intrinsic to instrumental and ecocentric to anthropogenic. A conceptual basis has been derived for the selection of variables and indicators that can be used to describe the most relevant ecosystem characteristics to assess ecosystem condition (described in detail in DP 2.3).

Criteria to select indicators that are appropriate to characterize the condition of ecosystems should include compliance with accounting principles, policy-relevance, and meaningful from a biophysical perspective. The following are the criteria for individual variables and their derived indicators: relevance, state orientation, framework conformity, spatial consistency, temporal consistency, feasibility, quantitativeness, reliability, normativity and simplicity. The following are ensemble criteria that are interpreted for the whole set of indicators: parsimony and data gaps (Table 1 in DP 2.3).

A comprehensive hierarchical classification of ecosystem condition variables and indicators or typology is described in DP 2.3 and is used to create a reporting and aggregation structure. The classification derives a set of ecosystem condition classes with the common aim of being broad and inclusive, so that all variables and indicators meet the above criteria, and conform to a unique class.

Table 2. Proposed typology for classification of ecosystem condition variables and indicators.

<table>
<tr><td rowspan="7">Ecosystem condition</td><td rowspan="2">Abiotic characteristics</td><td>Physical state</td></tr>
<tr><td>Chemical state</td></tr>
<tr><td rowspan="3">Biotic characteristics</td><td>Composition (including species-based indicators)</td></tr>
<tr><td>Structure (including vegetation, biomass, food chains)</td></tr>
<tr><td>Function (including ecosystem processes, disturbance regimes)</td></tr>
<tr><td rowspan="2">Landscape and seascape level characteristics</td><td>Landscape diversity of biotic or abiotic characteristics</td></tr>
<tr><td>Spatial distribution of characteristics such as connectivity, fragmentation</td></tr>
</table>

3.4.2 Selection of indicators

Selection of indicators should consider the characteristics of assets that determine fundamental ecological processes and their risk of change (Mace 2019). Indicators for ecosystem condition will be based on the classification of ecosystem types derived from the spatial units, and the typology for characteristics of ecosystem condition (DP 2.3). Additionally, the definition and classification of ecosystem services will influence the position of indicators within the accounting framework. Definitions and roles within the accounting framework are needed for intermediate and final services, ecosystem processes, inter-and intra-ecosystem flows, and pressure indicators. Condition of ecosystem assets is described by a set of characteristics and derived indicators that include some common or global indicators as well as some ecosystem type specific indicators.

The aim for a set of indicators would be to have a minimum of one indicator per class in the typology and to develop a tiered structure of indicators based on the typology, where the tier selected relates to the purpose of the accounts. Indicators are likely to be differentiated and related to intrinsic or instrumental values, and to natural and human-modified ecosystem types. The selection criteria (DP2.3) can be used to prioritise and provide guidance on selection of indicators.

Selection of indicators should prioritise those that reflect a role in ecosystem processes and hence contributing to whole-ecosystem functioning. 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.

Existing sets of indicators can be used as a guide. The European Union published a set of indicators to measure ecosystem condition (and pressures) for terrestrial freshwater and marine ecosystems (Maes et al., 2018). Based on a screening of 401 studies, Rendon et al. (2018) recorded the frequency of indicators that have been used to map and analyse the condition of ecosystems (Figure 4).

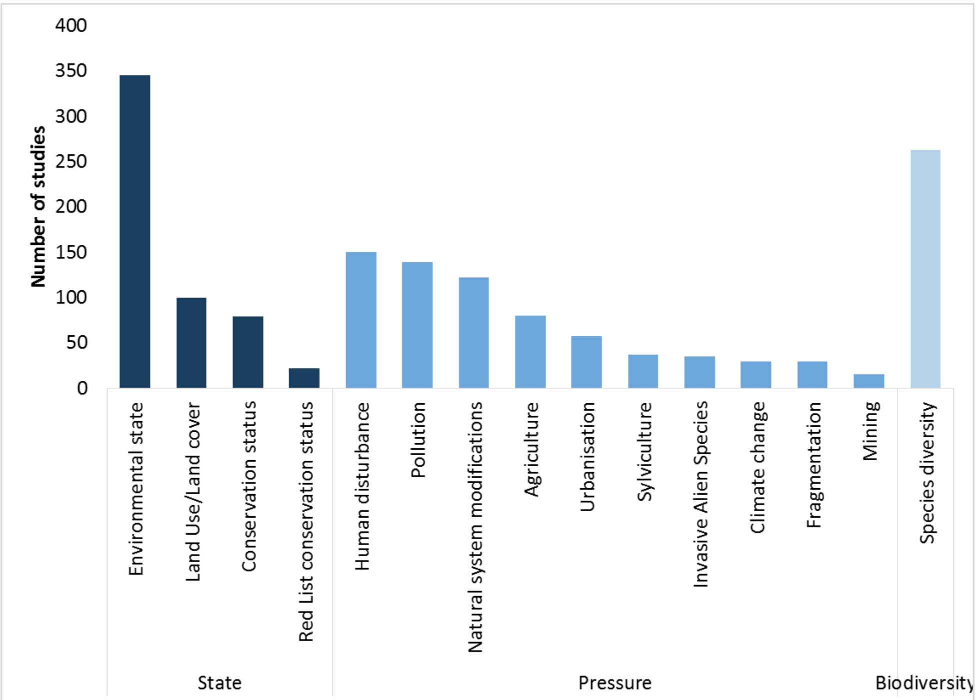

Figure 4. Types of indicators reviewed by Rendon et al. (2018).

Variables and indicators are selected to be sensitive to changes in ecosystem condition, but the form of this response may vary (Figure 5). The form of the response should be considered in the selection criteria, with a simple response (e.g. linear) preferred over a more complex one (e.g., bell shaped) (see selection criteria in DP 2.3). Many ecological processes, and their responses to human or environmental impacts, are non-linear with curvilinear and bimodal responses being common among ecological responses. For example, responses of plant growth to temperature or soil pH are bimodal, whereas the response of fish populations to water turbidity is negative curvilinear at an increasing rate. The form of these responses can be quantified and interpreted based on understanding of the ecological processes.

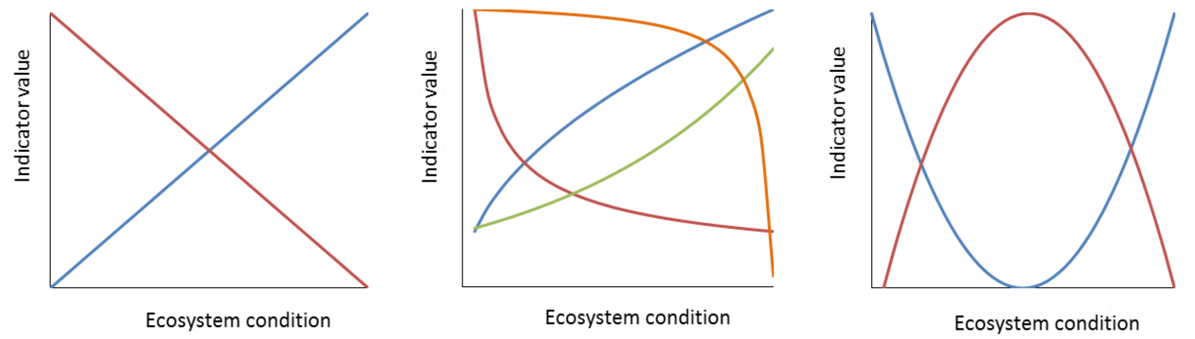

Figure 5 Response of indicator values to changing ecosystem condition

3.5 Outputs from ecosystem accounts

The outputs from ecosystem condition accounts can present the data for the spatial accounting units in the form of tables, maps and graphs. Tables display the quantitative data that can then be used in different forms. Maps are generally useful for displaying spatial distributions and graphs for displaying change over time. Ecosystem condition accounts developed for multiple purposes and containing different levels of metrics require a series of tables. Outputs can also consist of maps particularly to show spatial distributions, and figures and diagrams particularly to show change over time.

3.5.1 Condition account tables

The format of account tables varies for different metrics of variables, indicators and aggregated indices, with the following as examples. All the tables are organized with variables or indicators as rows and ecosystem types as columns. Any of these tables can evidently be transposed (rows instead of columns) if that facilitates interpretation of the data or formatting (e.g. in case of many ecosystem types). If required, all the tables can also contain the words "opening stock" and "closing stock" to indicate the accounting period. They can also contain additional rows for including the percentage change relative to a reference condition or to the opening stock value.

1. The use of variables, either individually or in a time series, provide an information system with a neutral approach. Ecosystem condition described by variables should be classified in neutral terms that do not imply a value judgement, for example high, medium, low biophysical quantities.

Table 3. Ecosystem condition accounting table reporting values for variables per ecosystem type for multiple years. The variables are grouped based on a typology for ecosystem condition indicators. This account can be used to assess the state of an ecosystem for a given year or to monitor and report change in variables over time as the state of ecosystem condition.

Class	Variables	Ecosystem types					
		Ecosystem type 1			Ecosystem type 2		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Class 1	Variable 1						
	Variable 2						
	Variable 3						
Class 2	Variable 4						
	Variable 5						
	Variable 6						

2. The use of indicators that are related to a reference level to infer the state of the ecosystem is a direct normative use of condition information for the purpose of informing policy on the state of ecosystem assets, as change from a reference condition or potential to gain a target for an anthropocentric condition. The reported values for the indicators do not differ, in principle, from the reported values of the variables in Table 4. Therefore, this table can also be used to monitor and report change in indicator values over time. These outputs can have either an ecocentric (for example, natural, semi-natural, modified, intensively modified) or anthropocentric worldview (for example, good or bad quality).

Table 4. Ecosystem condition accounting table reporting values for indicators per ecosystem type for multiple years. The indicators are grouped based on a typology for ecosystem condition indicators. For every ecosystem type and indicator, specific reference levels are provided against which values for indicators are compared.

Class	Indicators	Ecosystem types							
		Ecosystem type 1				Ecosystem type 2			
		Reference condition =				Reference condition =			
		Reference level	Year 1	Year 2	Year 3	Reference level	Year 1	Year 2	Year 3
Class 1	Indicator 1								
	Indicator 2								
	Indicator 3								
Class 2	Indicator 4								
	Indicator 5								
	Indicator 6								

3. Ecosystem condition indicators can be aggregated according to the typology to produce sub-indices that are related to an aggregated reference level. Aggregation can be by ecosystem types (a), or area (b). Aggregation can also be based on other schemes. The aggregated ecological condition index is related to the reference condition.

Table 5a. Ecosystem condition accounting table reporting values for aggregated indicators per ecosystem type for multiple years. The table contains for each class of the typology an aggregated sub-index. The aggregated sub-index for each ecosystem type can be compared with an aggregated reference level, which is here set at 100 for illustration purposes. The sub-index can also be compared with a reference condition specific to the extant ecosystem type. Each ecosystem type has an associate reference condition. For ecosystem type 1, the aggregated reference levels are the values at the reference condition. For ecosystem type 2, an anthropogenic condition is distinguished from the reference condition, appropriate for a human-modified ecosystem. Sub-indices are related to an aggregated target level that is less than 100. The table contains an ecological condition index which can be based on a second aggregation step (using the sub-indices) or on another aggregation scheme.

Class	Index	Ecosystem types							
		Ecosystem type 1 Reference condition =				Ecosystem type 2 Reference condition = Anthropogenic condition =			
		Aggregated reference level	Year 1	Year 2	Year 3	Aggregated target level	Year 1	Year 2	Year 3
Class 1	Sub index 1	100				75			
Class 2	Sub index 2	100				75			
Ecological condition index		100				75			

Table 5b. Ecosystem condition accounting table reporting the area of each ecosystem type that is covered by various ranges of ecosystem condition relative to the reference condition**.** Area values can be reported in absolute terms (e.g., ha) or in relative terms (as a percentage of the total surface area). For illustration purposes, three ranges of ecosystem condition are used: low, medium and high. Different threshold levels can be used based on different methodologies to define the range of each interval.

Class	Index	Ecosystem types							
		Ecosystem type 1				Ecosystem type 2			
		Condition interval relative to the reference condition	Area Year 1 (ha/%)	Area Year 2 (ha/%)	Area Year 3 (ha/%)	Condition interval relative to the reference condition	Area Year 1 (ha/%)	Area Year 2 (ha/%)	Area Year 3 (ha/%)
Class 1	Sub index 1	Low				Low			
		Medium				Medium			
		High				High			
Class 2	Sub index 2	Low				Low			
		Medium				Medium			
		High				High			
Ecological condition index		Low				Low			
		Medium				Medium			
		High				High			

3.5.2 Classification changes in ecosystem extent and ecosystem condition accounts

The ecosystem accounting framework requires a systematic approach in developing each account. The first step is the identification of spatial units and the ecosystem extent account, which involves mapping ecosystem type classes. The next step involves deriving the time series of ecosystem condition indicators for each ecosystem type. Ecosystem extent and condition can become conflated where ecosystem condition for a spatial unit changes to the degree of passing a threshold to a different ecosystem type, resulting in conversion from one ecosystem type to another.

A methodology describes how the ecosystem condition accounts are implemented for this case. When a step change in condition occurs that crosses a threshold defining a different ecosystem type, then a reclassification occurs and the ecosystem extent account is changed. Hence, the process is iterative in reconciling extent and condition. Examples of conversion of ecosystem types include clearing a native forest and replanting with trees to convert to a plantation, or convert to a grassland or cropland; draining a peatland and planting with trees to convert to a plantation; or land reclamation along a coastline to convert to built-up areas. These examples have clear thresholds upon which to define a change in ecosystem type. Other examples have less clear thresholds and are more difficult to define a change in ecosystem type, such as, a change in canopy cover below a threshold (but not zero) may be due to land use change that removed trees resulting in conversion from an ecosystem type of 'forest' to 'woodland'. However the reduced canopy cover could also be due to partial loss of leaves during drought and is reversible, with no influence of land use change.

The change in the spatial unit would be recorded as a change in ecosystem type in the ecosystem extent account, and the reclassification of this unit would follow through to the condition account. However, the reference condition for this spatial unit would remain fixed as its original state and the absolute change in condition would remain as the comparison with the original reference condition. In addition, the current condition of the new ecosystem type can be compared to an anthropocentric-derived condition as a relative change over time. For example, the conversion of forest to grassland would be recorded as a change in extent of ecosystem types with a reduction in area of forest and an increase in area of grassland. This new area of grassland would be recorded as 'derived grassland', where the reference condition was 'forest', in contrast to a 'natural grassland', and the anthropocentric condition was 'derived grassland' that has a set of target levels for indicators of condition appropriate to characteristics of a grassland ecosystem.

Change over time on an annual basis in condition indicators for the new ecosystem type, such as 'derived grassland', may be difficult to detect in relation to the original reference condition, such as 'forest'. Reporting on change in condition can be achieved by use of non-linear or broken scaling, as well as additional comparison against a new target level appropriate for the new ecosystem type that provides a meaningful scale for comparison. In the example of conversion of forest to grassland, assessment of condition using an indicator of soil carbon concentration could be compared against a reference level for forest as the opening stock of the reference condition, but also against a target level for grassland appropriate for annual comparisons for the new ecosystem type.

Challenges remain in cases where the boundary between ecosystem types is difficult to define in order to set a threshold for the condition indicators to identify the conversion from one ecosystem type to another. In the example, the canopy cover at which the ecosystem is no longer classified as a forest. Hence, rules are required to define change in ecosystem type and reclassification, which are likely to incorporate both thresholds in indicator values and the time over which change has occurred to determine permanence.

Table 6. Example of an extent and condition account when a spatial unit changes from one ecosystem type to another.

Case A: Ecosystem condition assessed against a reference condition.
In this example, the condition indicator for woody vegetation is canopy cover. The reference level for a Forest (1.00) is 100% canopy cover. In Forest 1a, canopy cover starts at 40% in Year 1 and declines so that in Year 2, 50 ha has a canopy cover of 40% and 50 ha has a canopy cover of 20% (Forest 1b). For assessment against the reference level, both areas are compared with 100% cover. The reference level for a Woodland (1.00) is equivalent to a canopy cover of 30%. Woodland 2a of 80 ha has a canopy cover of 15% and hence a condition of 0.50. In Year 2, 40 ha is cleared and so has 0 canopy cover. Assessment of the area-weighted average condition shows a decline in condition over time relative to the reference condition for the original vegetation types of Forest 1a and Woodland 2a.

Ecosystem type	Account	Reference level	Year 1	Year 2	Year 3	Year 4
Forest 1a	Extent (ha)		100	50	50	50
	Condition [0,1]	1.00	0.40	0.40	0.40	0.40
Forest 1b	Extent (ha)			50	50	50
	Condition [0,1]	1.00		0.20	0.20	0.20
Woodland 2a	Extent (ha)		80	80	40	40
	Condition [0,1]	1.00	0.50	0.50	0.50	0.50
Woodland 2b	Extent (ha)				40	40
	Condition [0,1]	1.00			0.00	0.00
Total area (ha)			180	180	180	180
Area-weighted average condition relative to reference condition			0.44	0.39	0.28	0.28

Case B: Classification of ecosystem types change and condition is assessed against a derived condition.
For the condition indicator for woody vegetation of canopy cover, the threshold for Forest is 30 – 100% cover, and for Woodland is 10 - 30% cover. The reference level for a Forest (1.00) is 100% canopy cover. In Forest 1a, canopy cover starts at 40% in Year 1 and declines so that in Year 2, 50 ha has a canopy cover of 20% and is reclassified as Derived Woodland 1b, and 50 ha has a canopy cover of 40% and remains as Forest 1a. The reference level for a Woodland (1.00) is equivalent to a canopy cover of 30%, hence the 50 ha of new derived woodland has a condition of 0.66. Derived Woodland 1b remains at a canopy cover of 20% for 3 years and this time period is used to determine a permanent change in ecosystem type (rather than a reversible change due to annual climate fluctuations). Woodland 2a of 80 ha has a canopy cover of 15% and hence a condition of 0.50. In

SEEA

Year 2, 40 ha is cleared and converted to Derived Grassland 2b. The target level for the anthropocentric-derived condition for grassland is 100% ground cover. Assessment of the area-weighted average condition shows an increase in condition over time relative to the derived condition for the new ecosystem types of Derived Woodland and Derived Grassland.

Ecosystem type	Account	Reference/ target level	Year 1	Year 2	Year 3	Year 4
Forest 1a	Extent (ha)		100	50	50	50
	Condition [0,1]	1.00	0.40	0.40	0.40	0.40
Derived Woodland 1b	Extent (ha)			50	50	50
	Condition [0,1]	1.00		0.66	0.66	0.66
Woodland 2a	Extent (ha)		80	80	40	40
	Condition [0,1]	1.00	0.50	0.50	0.50	0.50
Derived grassland 2b	Extent (ha)				40	40
	Condition [0,1]	1.00			1.00	1.00
Total area (ha)			180	180	180	180
Area-weighted average condition relative to derived condition			0.44	0.52	0.63	0.63

This example demonstrates that spatial units can be transferred from one ecosystem type to another when condition indicators cross a threshold. Condition indicators for the new, derived ecosystem types can be assessed against target levels that may be more appropriate for tracking change over time. However, it is important that the change from the original reference condition is recorded so that the overall state of the environment can be assessed.

4. Applications of ecosystem condition accounts

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 aggregate indices, 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.

Condition accounts are used to synthesize information about changes over time in the state of ecosystem assets (TR 7.52). 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 aggregated index) can be used to inform strategic planning at the national level. Because they are spatially explicit and include detailed information on particular characteristics of ecosystems, the accounts can also be used to inform landscape-level planning and site-level decision-making.

The use of variables, indicators, or ancillary information to assess the capacity of ecosystems to supply ecosystem services is an indirect normative use of condition information with an anthropocentric worldview 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.

Several examples demonstrate the range of applications of ecosystem accounts in providing information. Quantification of indicators and reference levels can be used to operationalize the definition of ecosystem degradation and restoration. Indicators of ecosystem condition combined with threshold levels can be used for assessing risk of change, or alternatively, assessing degree of resilience within ecosystems under conditions of change (SEEA EEA 4.21).

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).

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. International policies where the information from ecosystem condition accounts can be applied include greenhouse gas emissions reduction targets under the UNFCCC Paris Agreement (UN 2015), the Sustainable Development Goals (UN 2018), and the Aichi Biodiversity Targets (CBD 2010). In the Paris Agreement, the inclusion of the concept that ecosystem integrity must be promoted while accounting for national emissions reductions demonstrates significant progress in adopting an 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 the SDGs and Aichi Targets.

Derivation and application of a range of outputs can support different policy objectives, but it is important that the value framework and purpose be articulated. A condition account can support policy aimed at reaching a natural or undisturbed ecosystem condition, as well as policy aimed at reaching target levels associated with an anthropocentric condition, wanted by society, stakeholders or investors in ecosystem restoration. These policies have clearly different aims, and might apply in different parts of the landscape. Condition accounts should be able to support both policy aims by appropriate selection of variables and reference levels to derive indicators, reference conditions to derive aggregate indices, and interpretation of these indices in terms of thresholds.

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 simple indicators of the ecosystem that can be evaluated together with very different indicators representing economic, social, political and other realities. Accounting needs both the overview and the detail. Hence, individual indicators, sub-indices and indices of condition all have a role in the purpose and application of ecosystem condition accounts.

5. Challenges for ecosystem condition accounting

5.1 Selection of variables, indicators and indices

An appropriate breadth and detail of metrics selected to characterize ecosystem condition is difficult to define. The hierarchical typology described in DP 2.3, together with their criteria for selection, presents a pragmatic approach to encompass metrics for a range of scales.

Knowledge of local ecosystems is important for deciding upon appropriate metrics, and selection of metrics should be based on existing ecological knowledge and monitoring systems, with ecologists involved in the selection process.

A key question remains about the extent to which non-ecological variables should be included, for example pressures and drivers of ecosystem change, land use and management practices. These variables are often easier to quantify but only indirectly represent ecosystem condition. Pressures can be used sometimes as a proxy for condition, but should not be combined with direct indicators of condition. DP 2.3 discusses a broad range of relevant considerations in the form of selection criteria that are used to evaluate inclusion of variables, particularly in the context of the purpose of the condition accounts.

The characteristics of ecosystem assets, in terms of their state or ecological stocks and their change over time, should be measured as the condition variables. These provide more direct measures than derived measures from human activities that create pressures, drivers, or land management activities, including protected areas. Relationships between indicators based on human activities and the condition of ecological stocks can be difficult to define and may vary through space or time, for example, there is no inherent relationship between protection status and ecological condition. Pressures or land management activities are often not direct explanatory variables of changes in condition of ecosystem characteristics. A single pressure may affect more than one ecosystem characteristic, or alternatively, several pressures may interact to affect the condition of a single characteristic. Further, changes in condition as a stock can be detected without knowing the pressure or driver.

Dimensionality is a key issue in the selection of characteristics and their measured variables and indicators that are derived at different scales, and then the comparison and aggregation of these indicators across scales. Species diversity measured at local, regional or global scales is an example of the challenge in comparing these different metrics. Methods for identifying appropriate spatial and thematic aggregation, means of comparison and interpretation remain current research issues.

5.2 The role of biodiversity in ecosystem condition accounts

In the SEEA EEA, the definition of 'ecosystems' uses that 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*" (SEEA EEA 1.52). 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.

Biodiversity is defined in the SEEA EEA 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*" (SEEA EEA 2.7). 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.

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

(i) 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),
(ii) one or more characteristics or aggregated indices of biodiversity are often encapsulated in ecosystem condition accounts, which have a range of measurements as variables,
(iii) biodiversity metrics can provide indicators of intermediate or supporting ecosystem service flows.

In the Technical Recommendation, both biodiversity and habitats are included as characteristics in ecosystem condition accounts (Table 4.1). The perspective taken in the Technical Recommendations is that biodiversity is a characteristic of ecosystem assets that is most directly relevant in the measurements of the condition of ecosystem assets (TR 5.58). Measures of biodiversity, at all levels from species to ecosystems, are considered to relate primarily to the stocks component of the accounting model. These stocks can change over time, an attribute that applies only to ecosystem assets in an accounting context (TR 9.60).

The World Conservation Monitoring Centre has developed guidelines for the description of species accounts within the SEEA framework. The role of species within ecosystem accounts is described by King et al. (2016) as "*species and other aspects of biodiversity are key features of ecosystem condition*" and "*ecosystem condition characteristics include species assemblages*". Species selection and development of accounts can address different purposes for ecosystem condition or ecosystem services or conservation concern (King et al. 2016).

Species diversity is only one component of biodiversity that contribute to quantifying characteristics of ecosystem condition that occur at many scales. Biodiversity is not necessarily positively or linearly related to ecosystem condition for other purposes. For example, some of the most species-rich ecosystems, like shrublands in Mediterranean climates such as south-west Western Australia and south-western South Africa, have a low capacity to provide a range of ecosystem services due to infertile soils and low water availability, but a high biodiversity value.

There are no universally acknowledged metrics for biodiversity. Nevertheless, various metrics describing components of biodiversity can generally be positively associated with ecosystem integrity and ecosystem function (Haase et al. 2018), although may not be linear. Relationships depend very much on the components of biodiversity investigated (for example, species richness, abundance, functional richness, distribution) (Duncan et al. 2015). There are cases where biodiversity (in terms of species richness is naturally low but condition scores may be high or good.

The proposed typology of ecosystem condition metrics in DP2.3 includes various components of biodiversity within different classes. The highest-level classes are based on compositional, structural and functional characteristics, and spatial scales from local to global species diversity. Assessment of biodiversity across these scales is imperfectly nested, and hence cannot be upscaled or aggregated simply. A wide range of types of biodiversity indicators can be incorporated within the typology, for example, species abundance, species diversity metrics, presence / absence of single / key / iconic species, and functional metrics such as trophic level. Characteristics of ecosystems related to ecosystem processes and landscape pattern can incorporate both biotic and abiotic components. Many types of metrics describing different components of biodiversity are potentially useful to quantify these characteristics, with selection based on the purpose within the values framework and the criteria for appropriate metrics. The biodiversity indicators do not have to be assessed at the same spatial units or ecosystem types as other indicators, but do have to be spatially explicit across the ecosystem accounting area.

The ecosystem characteristics related to biodiversity that are included in condition accounts can address values relating to any of the perspectives described in Figure 2, and quantification can be in the form of variables, indicators or aggregate indices. By contrast, characteristics related to the capacity to supply ecosystem services must lie within the instrumental half of Figure 2.

Biodiversity is fundamental to the functioning of ecosystems, and hence the accounting for biodiversity should be integrated fully within the structure of the ecosystem accounts for extent, condition and services. Incorporating the interrelationships and feedbacks between biodiversity and ecosystem condition and services is critical. The role of biodiversity in determining ecosystem condition and the services provided can be described in terms of species traits or biological attributes, which influence the functioning of ecosystems. Functional classifications of species based on sets of traits, described in terms of their response to environmental factors, provide useful indicators of biodiversity and the relationship with ecosystem integrity (Lavorel et al. 1997, Cernansky 2017).

5.3 Assessment of change in extent and condition of ecosystem types

The condition of an ecosystem type can change to the degree that results in a conversion from one ecosystem type to another, for example gradual removal of trees and reduction in canopy cover to eventual clearing and development of a grassland. This conversion would be recorded as a change in extent of ecosystem types with a reduction in area of forest and an increase in area of grassland. This new area of grassland would be recorded as 'derived grassland', where the reference condition remains a 'forest', in contrast to a 'natural grassland'. Indicators of the derived grassland can be assessed against target levels associated with an anthropocentric-derived condition.

A key challenge remains for some cases where the boundary between ecosystem types is difficult to define in order to set a threshold for the condition indicators to identify the conversion from one ecosystem type to another. In the example, the threshold canopy cover needs to be defined at which the ecosystem is no longer classified as a forest. Hence, rules are required to define change in ecosystem type and reclassification, and often a time period over which the change must remain to be classified as a permanent change. The ecosystem accounting framework requires a systematic approach, starting with the identification of spatial units and the ecosystem extent account, involving mapping of ecosystem type classes. The next step involves deriving the time series of ecosystem condition indicators for each ecosystem type. When a step change in condition occurs by crossing a threshold that defines a different ecosystem type, then the spatial unit is reclassified and the ecosystem extent account is changed. Hence, the process is iterative in reconciling extent and condition.

Change over time on an annual basis in condition indicators for the new ecosystem type may be difficult to detect in relation to the original reference condition. Reporting on change in condition can be achieved by using non-linear or broken scaling, as well as additional comparisons against new target levels appropriate for the new ecosystem type. In the example of conversion of forest to grassland, assessment of condition using an indicator of soil carbon concentration could be compared against a reference level for forest as the opening stock of the reference condition, but also a target level for grassland appropriate for annual comparisons for the new ecosystem type.

5.4 Inference from ecosystem condition assessment

The different metrics in the condition account support different levels of inference. The rationale for selection of metrics should be transparent and explicit. Variables allow presentation of data and show trends over time. Indicators allow assessment of the data against a reference level. This provides a "score" but is not necessarily normative allowing inference of a value judgment.

If an anthropocentric-derived condition were employed in ecosystem accounting, then inference about quality, as a distance from target levels, would be a consequence. This may be beneficial for policy applications of ecosystem accounting, but the scientific objectivity of the process would need careful consideration. It is important to be transparent about the purpose(s) of the condition assessment.

6. Recommendations for SEEA EEA Revision

This section presents a selection of issues for further research in the SEEA EEA Technical Recommendations. Implementing these suggestions may also need a revision of the current definition of ecosystem condition but this has not been discussed in the context of this series of papers.

6.1 Purpose of ecosystem condition accounts

Initial identification and statement of the purpose of the ecosystem condition account is necessary. Based on the stated purpose of the account, the types and scales of spatial and site data sources, and the method of aggregation to reporting units should be described.

The purpose of ecosystem condition accounts is defined in terms of a two-dimensional values framework that incorporates intrinsic and instrumental values, and anthropogenic and ecocentric approaches. The purpose stated in the Technical Recommendations of the measurement of ecosystem condition to provide information about the capacity to provide flows of ecosystem services, is only one of a range of purposes that have now been defined (TR 4.2).

Providing a general values framework for ecosystem accounting allows broad implementation and application, but there should be a requirement for explicit description of the nature of the values as well as their quantification. This approach is preferred compared with a prescriptive classification of values and/or adding a new classification of values to the several existing in the literature.

It should be recognized that selection of the purpose of the accounts, the values they reflect, and the type of data, all affect the information presented in the accounts and its subsequent interpretation.

The suggestion that *'indicators reflecting ecosystem integrity could be included, for example indicators of fragmentation, resilience, naturalness and ecosystem diversity'* (TR 4.64) is supported and the concept and practicalities extended with definitions in DP 2.1 and the typology in DP 2.3.

The concept that '*ecosystem condition may be assessed independently of the use of the ecosystem, but, a priori, any given level of condition is not necessarily good or bad'* (SEEA EEA 4.19) provides an initial recognition of the different potential purposes of condition, which have been expanded and defined with the use of variables in the current discussion paper.

6.2 Relationship between ecosystem condition, ecosystem service capacity and the supply of ecosystem services. [TR 4.69]

Ecosystem condition measures should be more general and integrative than the capacity to supply specific ecosystem services. Characteristics of ecosystem condition, and their associated measured variables and indicators, should include more than those restricted to providing final ecosystem services used by humans. This should include indicators of intrinsic values of condition and the provision of intermediate ecosystem services, such as habitat.

Greater clarity is needed in the ecosystem accounting framework in defining the links from ecosystem processes and functions, to ecosystem services, to benefits. If ecosystem services are defined narrowly as final services, which are flows of goods and services as end-products of nature compatible with the national accounts (Boyd and Banzhaf 2007), then a role and location is needed within the ecosystem accounting framework for other ecosystem processes. These ecosystem processes include inter- and intra- ecosystem flows and intermediate services. Additionally, timeframes need to be expanded to include the condition of ecosystem assets that influences future or potential flows in order to assess the supply and use of ecosystem services in terms of sustainability. Benefits are derived from both stocks and flows from ecosystem assets, and so these links need to be transparent in the accounting framework such that evaluation or comparisons can include all forms of benefits.

6.3 Identifying indicators of ecosystem condition [SEEA EEA 4.10 and Tech Rec. 4.70]

Condition accounts are described as a framework (Figure 2) with information provided about characteristics, variables, indicators and aggregate indices. Variables and indicators are selected from the pool of available information based on criteria reflecting the purpose and the context of condition accounts. Each of these components need to be identified and the links between them defined.

This framework formalizes the approaches to measurement suggested in Tech Rec 4.40, and explicitly defines the relationships between the different metrics and their uses.

The level of aggregation of indicators needs to be defined, in terms of relating to individual characteristics or overall ecosystem function.

The statement that the relevance of ecosystem condition indicators depends on context (Tech Rec 4.8) is supported and expanded upon by distinguishing purposes, identifying criteria, and developing a typology of characteristics, variables and indicators that can be selected depending on the context.

Ecosystem condition accounts can be developed, reported and used in terms of individual indicators describing an ecosystem characteristic, or various levels of aggregation of sub-indices and indices of composite characteristics and ecosystem types. The level of indicators in this hierarchy does not need to conform the three approaches described in Tech Rec 4.2.

6.4 Choice of reference condition and reference levels [Tech Rec. 4.71]

Specific definitions are given in this paper for reference levels and reference conditions, which reflect the multidimensional nature of the ecosystem condition concept. The term reference level should be used to refer to a simple indicator, whereas reference condition should be used in connection to whole ecosystems (or a broad group of ecosystem characteristics), which can also be useful to define the values of aggregated indices.

Reference condition represents the condition of an ecosystem to maintain ecological integrity. A range of options is necessary for assessing condition given the variation in the degree of modification of ecosystems by humans, and the different objectives for management or their target states. Consequently, the purpose and choice of reference levels must be standardized (as much as possible), transparent, and assumptions stated explicitly. Using the reference condition as the natural state is preferred and recommended. The reference condition, and associated measured reference levels, should be neutral and not referring to an evaluation or use of the ecosystem.

Setting of target levels associated with anthropocentric-derived conditions requires expert opinion based on understanding of the ecosystem types, and therefore is preferably not used as a standard. These metrics can be used in subsequent assessments related explicitly to a purpose where the assumptions are stated. Target levels reflect a preference for a particular use of the ecosystem. They can be policy relevant but also subject to political bias, and hence may not be appropriate for use by national statistical agencies or for comparison between regions/countries.

Selection of a point in time or the opening stock in the accounting period (as recommended in Tech Rec 4.59) is probably the least desirable as it has little ecological meaning. Individual years are subject to variability and inconsistency between indicators or regions of accounting.The SEEA EEA does not use target conditions currently as a form of a reference condition (SEEA EEA 4.20). In this paper, a role for target levels associated with an anthropocentric-derived condition is considered as a form of assessing indicators within ecosystem condition accounts to encompass a broader range of purposes but clearly maintaining the distinction between natural and human-modified ecosystems. There are potential problems in setting target levels for human-modified ecosystems being influenced by policy objectives, and themselves changing over time.

6.5 Role of biodiversity

Biodiversity is included in the typology of ecosystem condition metrics in terms of various components of biodiversity within different classes that describe compositional, structural and functional characteristics of ecosystems, and include spatial scales from species to landscapes. Characteristics of ecosystems related to ecosystem processes and landscape pattern can incorporate both biotic and abiotic components.

A wide range of metrics describing different components of biodiversity is potentially useful to quantify these characteristics, with selection based on the purpose within the values framework and the criteria for appropriate metrics. Where the metrics relate to species, these are referred to as species-based indicators that quantify species diversity. Many other components of biodiversity are also relevant and contribute to quantifying characteristics of ecosystem condition, and should not be constrained to taxonomic units.

The ecosystem characteristics related to biodiversity that are included in condition accounts can address values relating to any of the perspectives described in the values framework (Figure 1).

6.6 Defining and measuring degradation

Ecosystem degradation is defined in relation to the decline in condition of an ecosystem asset as a result of economic and other human activity (SEEA EEA 4.31). This aligns with the approach in the SEEA Central Framework for the definition of depletion of natural resources and in the SNA for consumption of fixed capital (depreciation) of produced assets. The Technical Recommendations define degradation more specifically as reflecting a decline in the monetary value of the ecosystem asset based on the expected flow of ecosystem services or its capacity (TR7.46).

The proposed broad and inclusive framework for ecosystem condition can (and should) also be used as the basis for an operative definition of degradation as a ‘persistent decline in the condition of an ecosystem unit' – either with respect to a specific condition indicator, or in an aggregated sense. Degradation is determined from indicators in ecosystem condition accounts, where the variables measured are compared to a reference level from which negative change can be assessed. Degradation can be assessed in terms of any of the components of the condition account, using physical or monetary metrics.

Further work is required on the conceptual basis for defining degradation and appropriate metrics and reference levels for quantification and interpretation.

7. References

Ayers R, van den Berrgh J, Gowdy J 2001. Strong versus weak sustainability: economics, natural sciences, and consilience. Environ. Ethics 23 (2): 155 – 168.

Batavia C and Nelson MP 2017. For goodness sake! What is intrinsic value and why should we care? Biological Conservation 209: 366 – 376.

Bland, L.M., Keith, D.A., Miller, R.M., Murray, N.J. and Rodríguez, J.P. (eds.) (2017). Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria, Version 1.1. Gland, Switzerland: IUCN. ix + 99pp.

Bordt M 2015 Land and ecosystem condition and capacity. SEEA Experimental Ecosystem Accounting Technical Guidance. UNSD, UNEP, CBD

Boyd J and Banzhaf S 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63: 616 – 626.

Burkhard B and Maes J (eds) 2017. Mapping Ecosystem Services. Pensoft Publishers, Sofia, Bulgaria, 374 pp.

CBD 2010. Convention on Biological Diversity Strategic Plan 2011-2020, Aichi Biodiversity Targets. https://www.cbd.int/sp/targets/default.shtml

Cernansky R. 2017. The biodiversity revolution. Nature 546: 22 – 24.

CLARA 2018. Climate Land Ambition and Rights Alliance. Missing Pathways to 1.5 ˚C. The role of the land sector in ambitious climate action. https://www.climatelandambitionrightsalliance.org/report/

DellaSala D et al. 2018 Ecosystem Integrity. Elsevier topic with a selection of papers on ecosystem integrity: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ecosystem-integrity

Dorren LKA, Berger F, Imeson AC, Maier B, Rey F 2004. Integrity, stability and management of protection forests in the European Alps. For. Ecol. Manage. 195: 165 – 176.

Duncan C, Thompson JR, Pettorelli N 2015. The quest for a mechanistic understanding of biodiversity – ecosystem service relationships. Proc. R. Soc. B. 282:20151348.

Gibbons P, Briggs SV, Ayers DA et al. 2008. Rapidly quantifying reference conditions in modified landscapes. Biological Conservation 141: 2483 – 2493.

Haase P, Tonkin JD, Stoll S et al. 2018. The next generation of site-based long-term ecological monitoring: Linking essential biodiversity variables and ecosystem integrity. Science of the Total Environment 613-614: 1376 – 1384. https://www.sciencedirect.com/science/article/pii/S0048969717321095

Hickler T, Vohland K, Feehan J et al. 2012. Projecting the future distribution of European potential natural vegetation zones with a generalized, tree species-based dynamics vegetation model. Global Ecology and Biogeography 21: 50 – 63.

https://www.sciencedirect.com/science/article/pii/S0378112704002166

IPBES 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. ES Brondizio, J Settele, S Diaz, HT Ngo (eds). IPBES Secretariat, Bonn, Germany.

IUCN 2019. International Union for Conservation of Nature. Definitions Glossary. https://www.iucn.org/downloads/en_iucn__glossary_definitions.pdf

King S, Brown C, Harfoot M, Wilson L 2016. Exploring approaches for constructing species accounts in the context of the SEEA-EEA. UNEP-World Conservation Monitoring Centre, Cambridge, UK.

La Notte A, Vallecillo S, Marques A, Maes J 2019b. Beyond the economic boundaries to account for ecosystem services. Ecosystem Services 35: 116 – 129.

La Notte A, Vallecillo, Maes J 2019a. Capacity as “virtual stock” in ecosystem services accounting. Ecological Indicators 98: 158 – 163.

Lavorel S, McIntyre S, Landsberg J, Forbes TDA 1997. Plant functional classifications: from general groups to specific groups based on response to disturbance. TREE 12: 474 – 478.

Leopold A. 1944. Review of the wolves of North America. Journal of Forestry 42: 928 – 929.

Leopold A. 1949. A Sand County Almanac. Oxford University Press.

Mace G. 2019. The ecology of natural capital accounting. Oxford Review of Economic Policy 35(1): 54 – 67.

Mackey B., DellaSala, D.A., Kormos, C., Lindenmayer, D., Kumpel, N., Zimmerman, B., Hugh, S., Young, V., Foley, S., Arsenis, K. and Watson, J.E.M (2015) Policy options for the world’s primary forests in multilateral environmental agreements. *Conservation Letters* **8**, 139–147.

Mackey BG 2007. Ecological Integrity – A commitment to Life on Earth. In: The Earth Charter in Action. Ed. Corcoran PB. KIT 65 – 68. http://www.earthcharterinaction.org/invent/images/uploads/ENG-Mackey.pdf

Maes J, Teller A, Erhard M et al. 2018. Mapping and assessment of ecosystems and their services: an analytical framework for ecosystem condition. European Union, Luxembourg.

Millennium Ecosystem Assessment 2005. Ecosystems and human well-being. World Resources Institute, Washington DC. https://www.millenniumassessment.org/en/Index-2.html

Norton BG 1992 Sustainability, Human Welfare and Ecosystem Heath. Environmental Values 1: 97 – 111.

O’Brien A, Townsend K, Hale R, Sharley D, Pettigrove V 2016. How is ecosystem health defined? A critical review of freshwater and estuarine studies. Ecological Indicators 69: 722 – 729. https://www.sciencedirect.com/science/article/pii/S1470160X16302370

Palmer MA and Febria CM 2012. The heartbeat of ecosystems. Science 336: 1393 – 1394.

Potschin-Young M, Burkhard B, Czúcz B, Santos-Martín F (2018) Glossary of ecosystem services mapping and assessment terminology. One Ecosystem 3: e27110. https://doi.org/10.3897/oneeco.3.e27110

Principe, P. P., Bradley, P., Yee, S. H., Fisher, W. S., Johnson, E. D., Allen, P., & Campbell, D. E. (2012). Quantifying Coral Reef Ecosystem Services, EPA/600/R-(January), 158

Rapport DJ 1989 What constitutes ecosystem health? Perspec. Biol. Med.33: 120 – 132.

Rendon P, Erhard M, Maes J, Burkhard B. 2019. Analysis of trends in mapping and assessment of ecosystem condition in Europe. Ecosystems and People 15 (1): 156 – 172.

Roche PK and Campagne CS 2017. From ecosystem integrity to ecosystem condition: a continuity of concepts supporting different aspects of ecosystem sustainability. Current Opinion in Environmental Sustainability 29: 63 – 68.

Rockström J et al. 2009. A safe operating space for humanity. Nature 461: 472 – 475.

Saner MA and Bordt M. 2016 Building the consensus: The moral space of earth measurements. Ecological Economics 130: 74 – 81.

Schaeffer DJ, Henricks EE, Kerster HW 1988. Ecosystem health: Measuring ecosystem health. Environ. Manage. 12: 445 – 455.

Singer P. 2010. One Atmosphere. Ch 10 pp 181 – 199 In: Climate Ethics Essential Readings. (eds.) SM Gardiner, S Caney, D Jamieson, H Shue. Oxford University Press.

Stoddard JL, Larsen DP, Hawkins CP, Johnson RK, Norris RH 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4): 1267 – 1276.

Tilman D 1982. *Resource Competition and Community Structure*, Princeton University Press, Princeton, NJ.

Turner RK 2001. The place of economic values in environmental valuation. In: Valuing environmental preferences: theory and practice of the contingent valuation method in the US, EU, and developing countries. Eds IJ Bateman and KG Willis. Oxford Scholarship Online doi:10.1093/0199248915.003.0002.

United Nations (2017). Technical Recommendations in Support of the System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting. United Nations, New York. https://seea.un.org/sites/seea.un.org/files/technical_recommendations_in_support_of_the_seea_eea_final_white_cover.pdf

United Nations (2018) SEEA Experimental Ecosystem Accounting Revision 2020. Revision Issues Note. https://seea.un.org/sites/seea.un.org/files/documents/EEA/eea_2020_revision_issue_final_jul2018.pdf

United Nations 2018. Sustainable Development Goals. https://www.un.org/sustainabledevelopment/sustainable-development-goals/

United Nations Climate Change 2015. The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

United Nations, European Union, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development, World Bank (2012). System of Environmental-Economic Accounting 2012 — Experimental Ecosystem Accounting. United Nations, New York. https://seea.un.org/sites/seea.un.org/files/seea_eea_final_en_1.pdf

Vardon M and Harris R. 2017 Review of ecosystem condition indicators. London Group, October 2017 Costa Rica.

Walsh P and Wheeler W 2012. Water quality index aggregation and cost benefit analysis. US Environment Protection Agency Working Paper 07/2012 https://www.epa.gov/environmental-economics/working-paper-water-quality-index-aggregation-and-cost-benefit-analysis