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Research area #2: Ecosystem condition

Discussion paper 2.1: Purpose and role of ecosystem condition accounts

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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 level, 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 proposing 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 state. 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 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 overall quality of an ecosystem asset, in terms of its characteristics describing intrinsic and instrumental values*".

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 2.1. Ecosystem condition is assessed in physical terms.

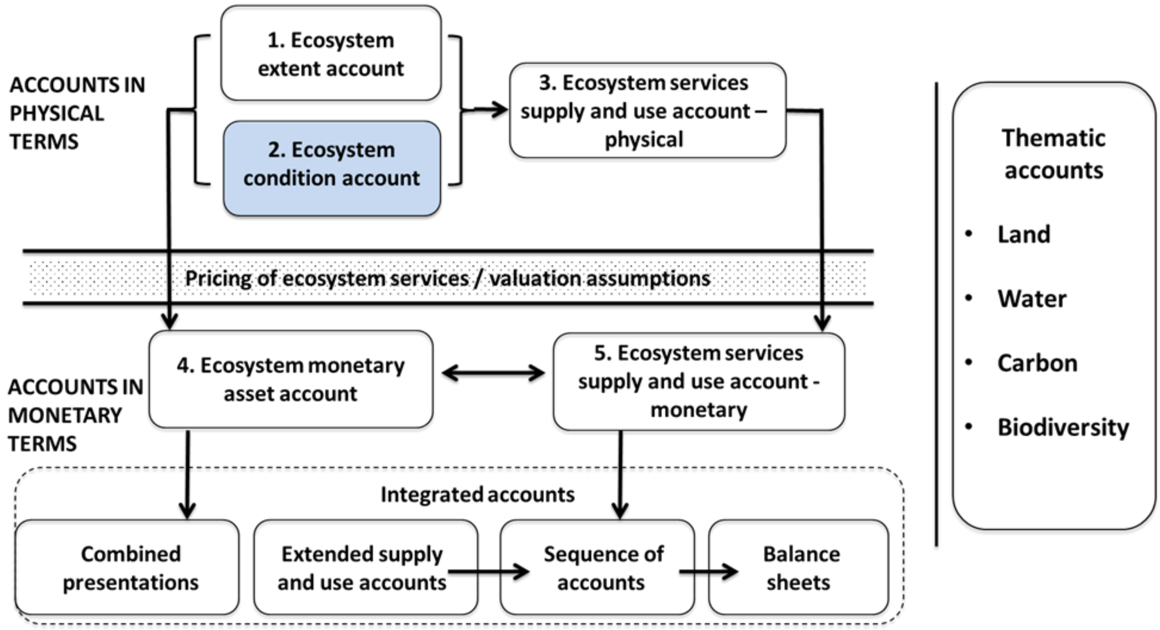

Figure 2.1. The position of ecosystem condition accounts within the ecosystem accounting framework. [modified from the Technical Recommendations by (i) not including Ecosystem Capacity which is not currently measured in terms of an account, and (ii) linking ecosystem extent and condition to the ecosystem 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.

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

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

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

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

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. 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 2.2) (adapted from the concepts in Turner 2001). 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 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.

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.

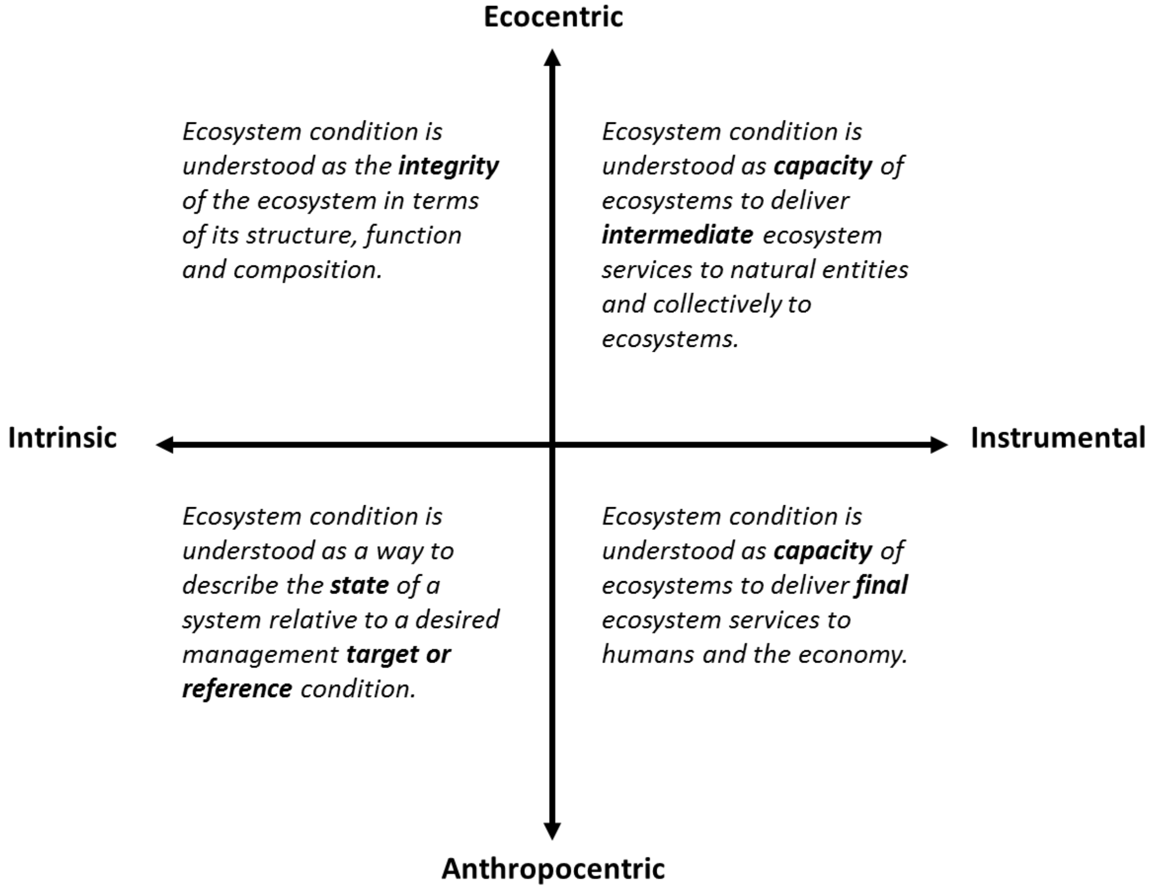

Figure 2.2 A general values framework in two dimensions representing the range from intrinsic to instrumental values and from ecocentric to anthropogenic world views (adapted from Turner, 2001)

The current description of the SEEA EEA is positioned mainly in the lower right quadrant of Figure 2.1 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 (or other desired) state. 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). Intrinsic 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, that of 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 a natural or desired state with associated 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.

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.

For a long time, environmental policies have been based on intrinsic arguments, non-use values and sometimes have embraced non-anthropocentric worldviews. 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 of ecosystem services contributing to the economy.

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 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 2.2). 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) *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. Some variables are sensitive to change and can be used to monitor and report changes in the state of ecosystem assets, and so can be included within an ecosystem condition account. Other variables are unlikely to change, for example elevation, and so are not included in a condition account but used as ancillary data (see Figure 2.2 and criteria in discussion paper 2.3).

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.

(iii) *Reference level* is a value against which it is meaningful to compare the current value of a variable in order to derive an indicator. A reference level applies to an individual indicator and is likely to differ for different ecosystem types. For example, the reference level for a biomass indicator such as normalized difference vegetation index (NDVI) can be different for a forest, savannah and grassland. Reference levels can be used in the normalization process necessary to generate aggregated indices of condition.

A reference level can be a value reflecting natural state, a temporal baseline (the indicator value for a particular point in time), a desired value (the indicator value that a policy aims to achieve), a prescribed value (such as a legislated quality measure), or a threshold value (an indicator value above or below which there is evidence that ecosystem condition is sub-optimal).

A reference level can be set with different options for the value, or threshold, depending on the purpose of the indicator for ecosystem condition. Hence, different indicators can be derived from the same variable when different reference levels are assigned.

(iv) *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".

(v) *Selection criteria* can be seen 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.

(vi) *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.

(vii) *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.

(viii) *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.

(ix) *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.

(x) *Reference condition* is a consistent set of reference levels across several ecosystem types, which is applied to aggregate indices of condition. Reference condition can be set in relation to a consistent set of categories or a single index across several ecosystem types. For example, the reference condition for forest, savannah, grassland, wetland and river ecosystem types could be “natural” or “100”.

According to this typology, 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.

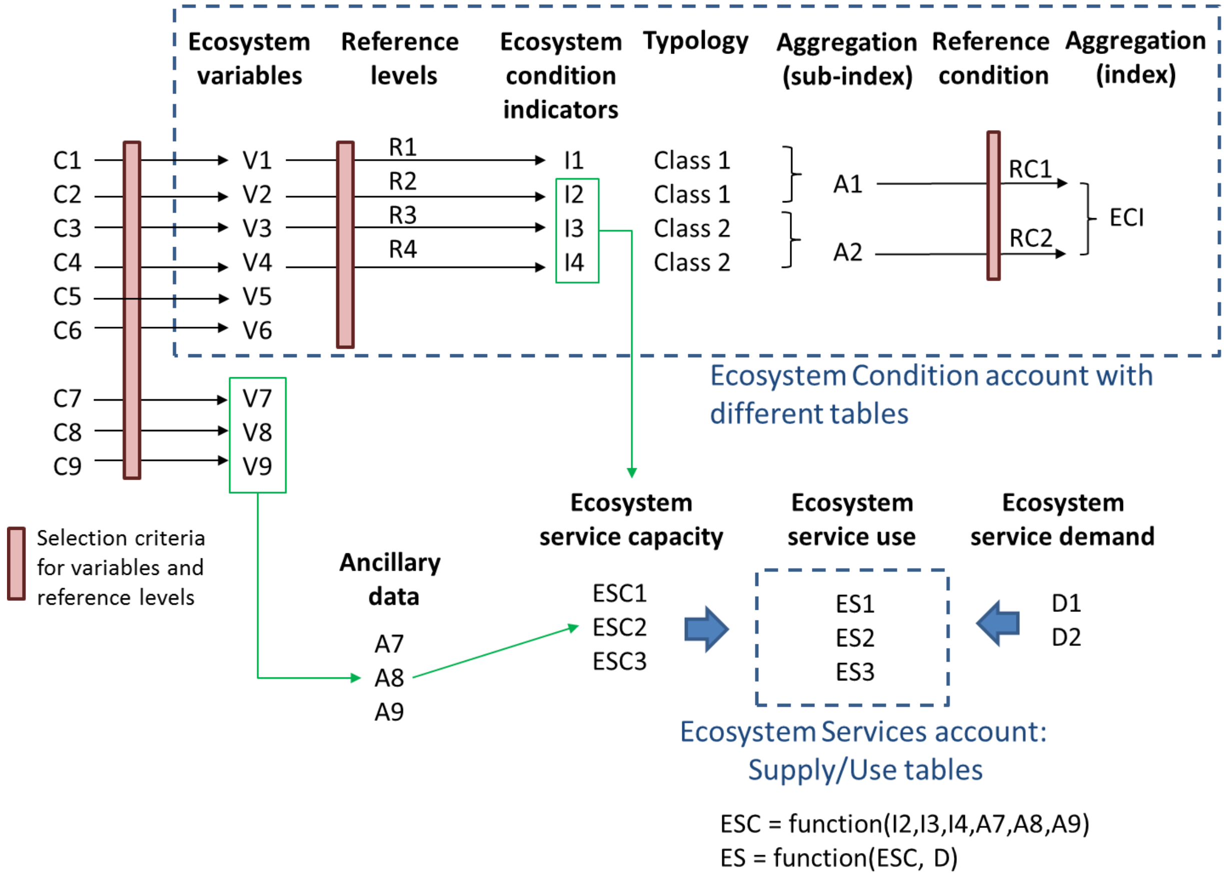

Figure 2.3. Components of an ecosystem condition account and relation with the ecosystem service account. The scheme starts with 9 ecosystem characteristics (C1, C2, …, C9). Ecosystem characteristics can be quantitatively measured by ecosystem variables (V1, V2, …, V9). In this scheme, for every ecosystem 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: therefore I5 and I6 are lacking from the scheme. Every indicator can be classified using a typology of 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 reference conditions (RC1 and RC2) 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 Responses of condition indicators

Variables and indicators are selected to be sensitive to changes in ecosystem condition, but the form of this response may vary (Figure 2.3). 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.

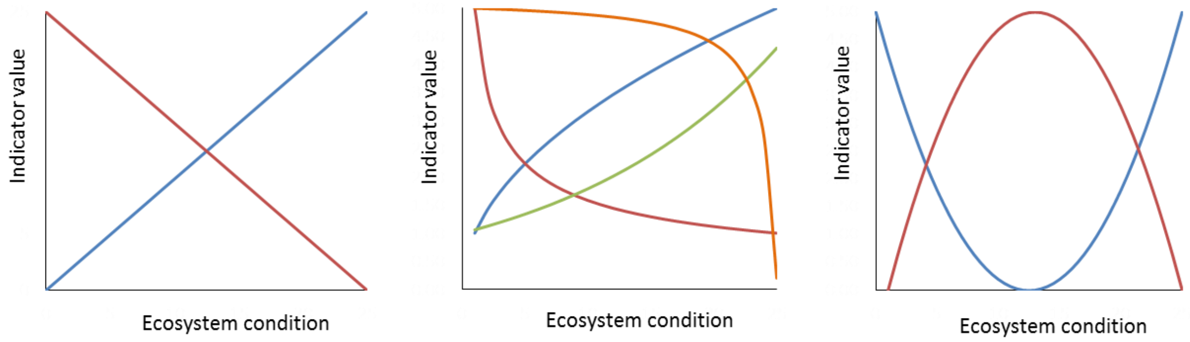

Figure 2.3 Response of indicator values to changing ecosystem condition

3.3.3 Aggregation of indicators

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. 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 several characteristics within an ecosystem type, and should be based on the typology of ecosystem condition variables (DP 2.3).

Aggregation is based on a hierarchy that is 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.

Indicators to be aggregated are assessed in terms of a reference condition to provide a common standard, weighted and combined to form a composite or index. Aggregation usually requires standardization of the data and selection of 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. Aggregate indices are related to reference conditions for the ecosystem type of accounting area. Some indicators are meaningful only when aggregated at larger scales, for example fragmentation, connectivity and some diversity indices.

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. 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.

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. For some purposes it is preferable to apply simple medians, modes, maximum, minimum statistics rather than means, rather than using methods of weighting and ranking. Among methods of weighting for aggregation, 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. The

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

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.

Further 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.

Aggregation and upscaling from individual characteristics and indicators are major research issues that require further consideration in the SEEA EEA Revision, but a sound basis for this research is provided by the typology.

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 2.2. The interface between the two concepts needs to be considered together to maintain internal consistency of the whole SEEA EEA accounting framework.

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. Proposed typology of ecosystem condition

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. The classes include: species-based indicators, vegetation and biomass, ecosystem processes, physical and chemical state, and landscape pattern.

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. The following series of tables provide examples for different metrics.

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 1. 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 state or potential to gain a desired state. The reported values for the indicators do not differ, in principle, from the reported values of the variables in Table 1. 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 2. 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, a reference level is provided against which values for indicators can be compared.

Class	Indicators	Ecosystem types							
		Ecosystem type 1				Ecosystem type 2			
		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 or indices that are related to a reference condition. Aggregation can be by ecosystem types (a), or area (b). Aggregation can also be based on other schemes.

Table 3a. 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 value can be compared with a reference condition, which is here set at 100 for illustration purposes. The table contains also a 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				Ecosystem type 2			
		Reference condition	Year 1	Year 2	Year 3	Reference condition	Year 1	Year 2	Year 3
Class 1	Sub index 1	100				100			
Class 2	Sub index 2	100				100			
Ecological condition index		100				100			

Table 3b. 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	Area Year 1 (ha/%)	Area Year 2 (ha/%)	Area Year 3 (ha/%)	Condition interval relative to the reference	Area Year 1 (ha/%)	Area Year 2 (ha/%)	Area Year 3 (ha/%)

		condition				condition			
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			

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 a desired state, 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.

Methods for identifying appropriate spatial and thematic aggregation, means of comparison and interpretation remain a current research issue.

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 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.

The ecosystem characteristics related to biodiversity that are included in condition accounts can address values relating to any of the perspectives described in Figure 2.1, 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 2.1.

5.3 Assessment of change

Ecosystem condition is assessed in terms of change in the measured indicators over time and compared with a reference level. Change in aggregate indices comparing ecosystem types is determined in relation to a common reference condition. Comparison of states of condition on a normalized scale, for example from 0 to 1, needs to have reference levels or reference conditions at both ends of this scale.

Determining appropriate and explicit reference levels and reference conditions can be difficult and describing the rationale for their selection is important. Options for types of reference levels and reference conditions include:

- (i) natural state, in terms of:
  - a) undisturbed by human activities. This is sometimes defined as a pre-industrial state. Undisturbed can be problematic for anthropogenic ecosystems and for areas where the ecosystem (type) changes.
  - b) a stable or resilient state. This state can be assessed through monitoring and is often defined by a level of tolerable change or risks. However, this category should only be used as a reference if this state can be defined.
- (ii) temporal baseline, in terms of:
  - a) a single point in time to assess all characteristics of ecosystem condition
  - b) the beginning of an accounting period, although this is difficult to compare across different characteristics, different periods and different regions, and results in a shifting baseline that is not recommended
  - c) the earliest date for which consistent or reasonably comprehensive data are available
- (iii) statistical approaches based on analysis of the range in indicator values derived from current condition. Statistical approaches may involve normalizing with the maximum values of available data for indicators, which leads to similar comparability and consistency issues.
- (iv) prescribed values, in terms of:
  - (a) legislated quality measure
  - (b) expert judgement
- (v) desired state or target level can be used in relation to specific reference levels, including
  - a) a desired state may take into account social, economic and environmental considerations and reflect preferences for a particular use of an ecosystem.
  - b) a reference level quantifying an undesirable state can be required to define the zero end of the normalized scale. Such a state can include where the ecosystem is no longer present or functioning, or has passed a threshold where the ecosystem asset has changed.
  - c) a threshold value where there is evidence that an indicator value above or below the threshold represents sub-optimal ecosystem condition.

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. 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 a target or desired condition were employed as a reference in ecosystem accounting, then inference about quality, as a distance from the desired condition, 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.

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.

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.

Further work is required to define the roles and interactions of these sections within the framework of ecosystem accounting.

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

Condition accounts are described as a framework (Figure 2.2) 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.

Choice of reference condition [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 level and condition can refer to a natural state, a desired state, a prescribed or standard state, a historical state or a point in time. These serve different purposes and both purpose and choice of reference level must be stated explicitly. Selection of the reference level will depend on the purpose of the accounts and data available, but 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.

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 conditions or desired states as a form of reference in the ecosystem condition accounts has been suggested as a means of encompassing a broader range of purposes for reference conditions. There are potential problems of desired states being influenced by policy objectives, and themselves changing over time. It is recommended that this role be re-considered and possibly that desired states be used outside the condition accounts in the process of analysis of the condition metrics as part of applications.

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 2.1).

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 from a desired state 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.

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