The SEEA Experimental Ecosystem Accounting framework: Structure, Challenges, and Links with the Nature Index.

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Grégoire Certain[1,2], Signe Nybø[1], David Barton[1], Bård Perdersen[1], Olav Skarpaas[1], Iulie Aslaksen[3] & Per Arild Gårnasjordet[3]

1-Norwegian Institute for Nature Research, Trondheim, Norway ; 2- Institute of Marine Research, Tromsø, Norway; 3-Statistics Norway –Oslo, Norway.

The structure of the SEEA Ecosystem Accounting framework.

Integrating Ecological and Economical Sciences within an accounting framework is an important step to include environmental considerations in the various decision-making processes carried out at national and international level by political, economic and financial institutions and that are usually mostly based on monetary aspects. The purpose of the SEEA Experimental Ecosystem Accounting (thereafter SEEA-EEA) is to be able to synthesize information on ecosystem in the form of "assets" in a way that respect fundamental properties but should ultimately allows the conversion of ecosystem services into monetary terms. In practice, the framework is strongly influenced by the work on land use in terrestrial systems supported by satellite-derived and GIS-processed information.

The ultimate goal of the SEEA-EEA framework is to develop an accounting structure to integrate environmental and economic information together to inform various policy discussions. It aims at (i) organizing environmental information according to (ii) a common, coherent and integrated set of concepts allowing (iii) connections between environmental and economic information and (iv) the identification of information gaps and requirements. It is worth noting that objectives (i), (ii), and (iv) are also clear objectives of the Nature Index framework, but objective (iii) which integrates the connection to economy, achieved through the concept of ecosystem services is a major difference between NI and SEEA-EEA.

The central structure of the SEEA-EEA framework (fig 1) is the "ecosystem asset", i.e. spatial areas containing a combination of biotic and abiotic components and other environmental characteristics. These ecosystems assets can be defined in term of their *condition*, *extent*, and *services*. Ecosystem *condition* can be decomposed in a number of *characteristics*, each of which being measured through a set of *indicators*. Ecosystem *extent* can be expressed at different conceptual scales for different practical approaches, either *Basic Spatial Units (BSU)* representing a finer, gridded spatial scale classically used as basic information support in GIS-related studies, *Land Cover Ecosystem Unit (LCEU)* i.e. distinct spatial entities characterized by their relative biotic and abiotic homogeneity, i.e. the predominant type of major ecosystem, or *Ecosystem Accounting Unit (EAU)* that are the spatial areas defined by administrative or land management boundaries (e.g municipalities or watershed areas). Finally, each ecosystem asset is supposed to provide the ecological capacity to produce a *basket of ecosystem services*, i.e. a set of *provisioning*, *regulating*, *cultural* or *supporting* services. This classification of services follows the CICES – Common International Classification of Ecosystem Services. *Provisioning services* reflect material and energy contributions of the ecosystems, *regulating services* result from the capacity of ecosystems to regulate climate, hydrological and bio-geochemical cycles and a broad variety of biological processes, while *cultural services* are generated from the physical settings, locations or situations giving rise to recreational, intellectual or symbolic benefit. *Supporting services* represent the broad range of underlying biological and ecological processes involved in the production of the three other service categories but as they do not directly result in benefits, the SEEA-EEA framework suggests they should not be the main target of accounting. The framework finally classifies the benefits produced by provisioning ecosystem services in two categories, whether they concern economic benefits measured in market values (*SNA benefits*) or non-market values (*non-SNA benefits*). Whatever the scale or concept considered (asset, service, indicator, etc…) the ecosystem accounting is supposed to be expressed in term of *stocks* and *flows*, which constitutes a direct transposition of the classical economic logic. These stocks and flows can exist within and between conditions, areas, and services.

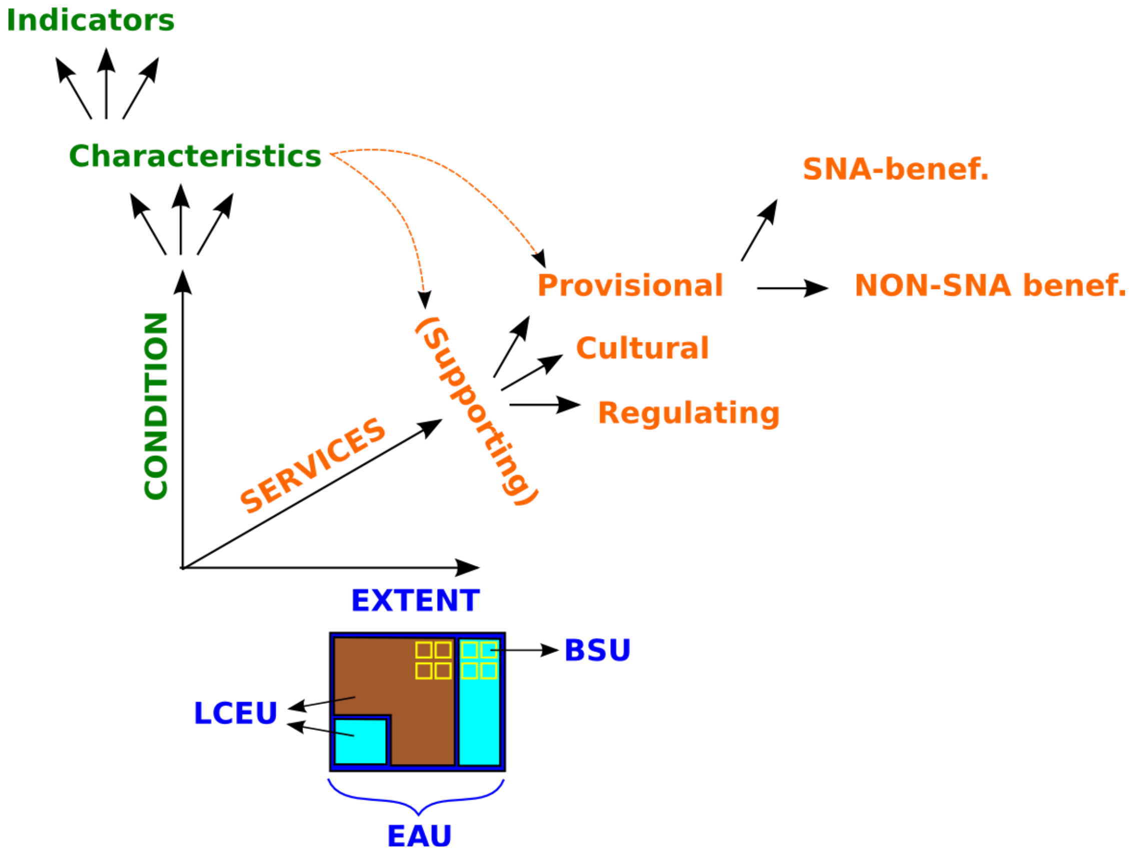

Fig 1. Hierarchical organization of concepts for the assessment of an ecosystem asset.

The SEEA-EEA framework recognizes that establishing an accounting framework organized according to the above-mentioned structure and concepts is an operational challenge. Difficulty will arise due to (i) heterogeneities in information sources, data availability, research traditions, (ii) non-linear dependencies between the different elements of the framework, and (iii) discrepancies between the amount of information required and available at hand, probably resulting in numerous assumptions and simplifications.

The main advantage of the framework is clear and lies in its integrative capacity and the attempt of explicitly formulating the link between ecology and economy, through introducing ecological measures of ecosystem condition, somehow related to the capacity to provide ecosystem services and associated benefits. The framework recognizes important features of ecosystems, such as their complexity, their non-linearities and their ability to regenerate, and provides an approach to conceptualize ecosystem qualities through a combination of extent and condition. Overall, the framework offers a consistent hierarchy of concepts to organize ecological information and transmits it in an economic form through a strong emphasis on the relationship between ecosystem condition and ecosystem services. Since this conceptual organization is summarized above and described at length in the main document, we will not discuss it further. Rather, we will focus in the following sections on a suite of questions, challenges, theoretical and practical problems raised by the framework, and we will propose some solutions, in order to generate constructive discussions dealing with the application of the framework in various countries and areas.

Challenges of the SEEA ecosystem accounting framework

A strong emphasis on the BSU

Challenge: The SEEA-EEA framework defines the BSU as squares of small areas (1km2, 1 ha, sometimes even less) delimited to be "as small as possible given available information and landscape diversity". Each BSU is supposed to have an exhaustive set of information, including spatial location, land cover type, and information relevant for accounting such as ecosystem characteristics, species abundance, ecosystem services. The framework recognizes that these information are often generated at larger scale and therefore that some downscaling method will be needed.

The first challenge of having such a strong emphasis on a very fine scale is that it can prevent in practice the inclusion of any information collected at larger scale, which is the case of nearly all ecological information collected in the field. Ecological field data are collected according to varying site-based or transect-based sampling schemes that can't be carried out at such fine scales. In fact, the BSU scale is mostly relevant for information provided by satellite imagery, for example land-cover classification. Satellite imagery is useful information, but it will never replace field observations as it will never provide accurate data on species distribution, composition, abundance, physiology, demography, behavior, which are of crucial importance for the assessment of ecosystem condition and ecosystem services but will be rarely, if ever, be available at the BSU scale due to sampling constraints. If the accounting framework strongly depends on the capacity to link information at the BSU scale, the risk is that information produced at larger scale will simply be dismissed, leaving satellite-derived information as the sole information source for accounting. For ecosystem services that mostly depend on land use and vegetation type, such as timber production, this may be a reasonable practice. But for services that strongly depend on species composition, interaction and abundances, such as pollination, hunting, fishing, or cultural services provided by flagship species, solely relying on satellite imagery can lead to great errors.

The second challenge is more fundamental as it concern the BSU definition itself. According to the framework, the BSU can be related to only one type of LCEU, which is simply unrealistic. Even by reducing the scale to the finest possible grid, there will always be conflict and need for pragmatic and operational trade-off with this definitions, as ecosystem types can be intermingled into each other at multiple scales. The simplest example of such a problem is to think about a river moving through a forest. Even with the smallest possible pixels, it is highly unlikely that a given pixel will be solely composed of a river, and another one solely composed of forest. Whatever the scale chosen for the pixels, the problem will always remain as it results from the fundamental difference between the rasterised nature of any grid and the vectorial nature of landscapes. One pragmatic solution one can think of is to reduce the pixel size as much as possible, as it is advocated in the SEEA-EEA handbook. But in practice, such a solution may lead to other operational problems, as very small BSUs will require highly demanding GIS-resources to be managed, that is more time, higher costs, and less flexibility.

The third challenge with the definition of the BSU is that it applies only to terrestrial landscape, where high-resolution satellite imagery is available. With marine areas, the BSU concept is clearly not applicable, simply because of the dynamical nature of the oceanic landscape. In the marine areas, it is likely that solely the concepts of EAU and LCEU will be of use, with the limitation that the name “Land Cover Ecosystem Unit” does not make sense for marine ecosystems and should probably be reworded.

<u>Proposed solution:</u> Simply relaxing the constraints or emphasis on the BSU, recognizing that such a scale is indeed convenient for the purpose of synthesizing satellite-derived information, but is not appropriate for the synthesis of all field-based ecological information. As an alternative to the BSU, the EAU could be used as the common spatial unit to aggregate the information from different LCEUs in the accounting process. EAU do not need to be very large, but large enough to include several types of LCEU, and small enough to still allow a clear localization at a national scale. As advocated in the handbook, the use of administrative boundary for the definition of EAU is probably a wise choice, especially because it also makes the link toward economy and management much more straightforward. Finally, the vectorial nature of the landscape should be recognized explicitly, for example by measuring how much proportion of each EAU is covered by which LCEU. This type of method is already largely developed within satellite imagery and this should be straightforward.

The place of biodiversity in the definition of ecosystem condition.

<u>Challenge:</u> According to the SEEA-EEA framework, accounting for ecosystem *condition* can be achieved through assessment of various ecosystem *characteristics*, each of which being measured by a set of well chosen *indicators*. The framework proposes to use a LCEU (row) by Characteristic (column) table structure to account for ecosystem condition. The way it is presented in the framework, it implies that the same set of characteristics is relevant for all LCEU, which is a rather constraining assumption. In fact, it is highly likely that the set of relevant characteristic will be specific to each LCEU, even if some common characteristics can be identified as well. In the current framework, 5 main characteristics are

proposed, namely vegetation, biodiversity, soil, water, and carbon. No explanations are provided to justify this choice, which can be an easy target for criticisms from the ecological research community. One main criticism will probably refer to the place dedicated to biodiversity – a characteristic set up separately from the four other ones in the SEEA-EEA, and therefore supposedly independent, at least to some extent. The problem is that biodiversity clearly matters for all ecosystem characteristics. The diversity of plant species is a strong determinant for vegetation structure. As plant diversity also affects primary production it also matters for carbon storage. The health of soil systems is largely driven by the biodiversity of the soil macro and micro fauna, as water quality is often driven by and measured through the diversity of plants, fish and invertebrates being found in lake and rivers. In fact, it is very difficult to find any ecosystem characteristics that would not depend on biodiversity.

Proposed solution: Recognizing that biodiversity, instead of being one ecosystem characteristic among others, is a central umbrella concept for measuring ecosystem condition. All ecosystem characteristics should, either directly or indirectly, link to biodiversity. This is all the more important because biodiversity also strongly matters for the provision of many, if not all, ecosystem services. Furthermore, it would be important to recognize that the type of characteristics will be specific to LCEU, and therefore suggesting that dedicated expert panels should be responsible for their identification, instead of providing an arbitrary classification. At the very least, it should made clear that the proposed characteristics in the SEEA-EEA are solely mentioned for the purpose of example. Lastly, specific accounting table should probably be prepared independently for each LCEU.

Mixing service capacity and service use

Challenge: In the SEEA-EEA framework, ecosystem services are defined as the contribution to benefits and should be measured only when benefits can be identified. In other words, ecosystem services do not exists if it can’t be proven that they are providing benefits in one way or another to some elements of the human society. This leads to statements such as “For instance, air filtration by vegetation only materialises as an ecosystem service if there is air pollution in the atmosphere that the vegetation is absorbing and if there are people living nearby that benefit from a lower concentration of air pollutants”. This means that if there is no polluted air, if no one is breathing it, or if no one cares about the fact that some people are breathing polluted air, then the framework considers that no service is provided. One can easily see the pitfalls of such an approach, as proving the existence of benefits might be very difficult, subjective and controversial in many situations. Furthermore, when a service is decreasing, it is difficult to know right away if this is due to a decrease in the provision of the service or a decrease in its consumption. This is recognized in the paragraph dedicated to ecosystem degradation and enhancement (which could be reworded *asset* enhancement or degradation) but no solution is provided.

Proposed solution: Explicitly disentangling capacity of service provision and actual flow of service use in the framework. This requires a slight conceptual refinement, recognizing that ecosystems provide continuously a certain quantity of services, of which only a fraction actually flows towards users and generates benefits. But this would allow the accounting framework to track explicitly and jointly changes in capacity and flow of ecosystem services, ultimately offering a better support for decision making. This is all the more important that ecosystem condition is likely to affect service capacity, while the flow is more likely to be affected by user abundance and behaviour.

Time-dependent reference condition.

Challenge: For the purpose of aggregating measures of ecosystem condition and services, the framework discuss the use of reference conditions for indicators, allowing to scale different metrics on a common range of values before aggregation. The framework suggests that the reference condition should be related to a given point in time, either the beginning of an accounting period or a given time such as a pre-industrial benchmark. It furthermore stresses that ideally the chosen reference should be the same for all indicators and all LCEU. If intuitive from an accounting point of view, the notion of common reference point in time contradicts ecological theory and is intractable practically. The theory of ecology and evolution is very clear about the fact that there is nothing such as a stable ecosystem always at equilibrium that would remain continuously in the same state. Species move, appear and disappear, ecosystem are continuously reorganizing themselves to cope with changes in the biotic and abiotic constraints they are submitted to, and therefore one should not expect ecosystems to stay in a given state. Furthermore, searching for a time period suitable for a reference state that fits all LCEUs will raise strong practical difficulties. The 20^{th} century has indeed been marked by the industrialization process, but strong pressures on ecosystems were exerted much before. For example as a consequence of hunting, the moose population in Norway was already highly depleted in the beginning of the 20^{th} century, before industrialization even started. In Europe, rivers were highly polluted in the late 19^{th} and early 20^{th} due to uncontrolled anthropogenic discharges, and forests were almost completely depleted in the 17^{th} century due to a very resource-demanding wooden ship construction industry. Virtually no ecological data exists on the state of ecosystems beyond the 20^{th} century, so that our perception of the state of nature at these times is highly incomplete, making the definition of a reference even more difficult. These few examples only constitute the surface of an iceberg of problems that will inevitably rise as soon as one try to search for a common reference back in time, which ultimately will prevent the accounting structure from being operational.

Proposed solution: Two major top down constraints on the establishment of reference condition should be relaxed, namely the need to be attributed to a given point in time, and the need to refer to the same situation for all indicators and all LCEUs. At least, they should be relaxed during the first steps of implementation of the SEEA-EEA. Instead, the use of a flexible, step by step bottom-up approach should be recommended. First, reference levels should be established independently, indicators by indicators, using theoretical definitions about the kind of situation the reference level should refer to. What should be the state of biodiversity, the amount of services provided, or the extinction risk of the indicator at the reference state, and what is the numerical value satisfying these criteria. Second, once reference values have been defined for all indicators belonging to a given LCEU, they can be brought together, discussed and refined so that to reduce inconsistencies between them, if they exists. Indeed, it is important to ensure that the ecosystem state in which all indicators have reached their reference values corresponds to a state that is viable, at least theoretically, so that to ease the interpretation of the observed values and states. If necessary, the same harmonization process can be repeated across LCEUs. In order to guide these discussion and harmonization processes, the top-down objective of having reference levels referring to a common situation will be useful.

How the Nature Index framework can help to implement the SEEA experimental ecosystem accounting

Correspondence between NI and SEEA-EEA

There are numerous points of correspondence between the NI framework and the SEEA-EEA framework. As mentioned above, the two frameworks have common objectives such as the assessment of ecosystem condition and lack of knowledge. The LCEUs of the SEEA-EEA framework are the major ecosystems of the NI framework. When implementing the NI framework in Norway, municipalities have been chosen to be the EAUs, *i.e.* the spatial units defined for assessment purpose in the SEEA-EEA, for the reason that they are small enough to be considered as spatially accurate, large enough to integrate some natural variability that is not really relevant for accounting, and they also match a socially-defined boundary that makes transposition into economic and social science straightforward.

The SEEA-EEA framework recognizes the need for (1) scaling by reference condition and (2) weighting in order to be able to aggregate indicator values. The NI framework has established such a general scaling and weighting system. It can be applied to any kind of indicators and ecosystems, it respects major ecological properties such as the trophic and functional organization of species within ecosystems, and it also copes with heterogeneities in research effort, tradition and data quality across LCEUs.

There are some differences between NI and SEEA-EEA. The SEEA-EEA framework suggests the use of the BSU scale to aggregate/disaggregate information, while the NI framework achieves this at the EAU scale. The SEEA-EEA framework proposes to assess ecosystem condition according to a set of predetermined characteristics for which indicators have been carefully selected, while the NI framework is based on a very broad set of indicators referring to any aspect of biodiversity, gather and synthesizes the available information on these indicators and then combine it into thematic indices, when relevant. These thematic indices can be seen as pragmatic realizations of the ecosystem characteristics in the SEEA-EEA, but they can also focus on other aspects such as conservation or knowledge gaps. In that aspect, the NI is much more flexible and operational than the SEEA-EEA, as it builds from the whole information set already available within the ecological research network, rather than trying to design beforehand “perfect” indicators sets for which information may not be available in practice. The NI uses satellite-derived information to measure ecosystem extent within each EAU, in order to produce the classical condition*extent graphs used in the Natural Capital Index framework. However, the NI does not require much –if any- downscaling of information at the BSU scale. There is no reference level within the NI framework concerning the extent of each major ecosystem. Instead, the NI states that when a major ecosystem (LCEU) is present in a municipality (EAU) each ecosystem should be present in a good state in every municipality, which implies that they all should cover a “minimum” extent that may be understood as the smallest extent still ensuring a high capacity of supporting services. But the precise value of this minimum extent has not been explicitly calculated, and has been left to the appreciation of the experts documenting the indicators.

Using the NI within the SEEA-EEA framework

The SEEA-EEA framework is organized around three fundamental aspects: Ecosystem condition, extent, and service. From our reviews of complementarity between the two approaches, we suggest that the NI framework should be used to measure and track changes in ecosystem condition (fig 2). Indeed, the NI provides a robust framework to identify, scale, weight and combine indicators across any ecosystems to score the state in which ecosystems are in a particular EAU (municipality) as well as to produce thematic indices that may focus on supporting services, conservational aspects, knowledge gaps, or any other theme relevant for the ecosystem being assessed. Because the NI also has a statistical component, it is a well-designed tool to track and interpret temporal changes, as it can produces confidence intervals.

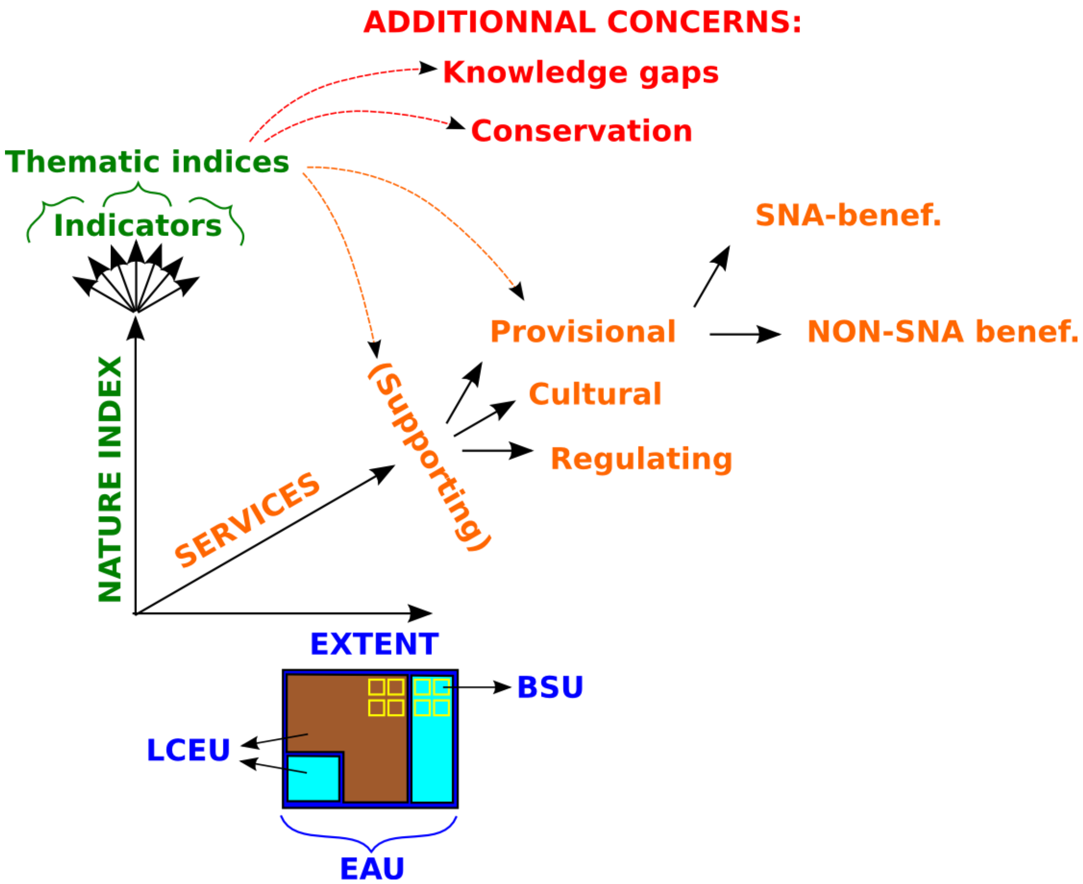

Fig 2. Contribution of the Nature Index to the SEEA ecosystem accounting framework: Accounting for ecosystem condition.

Concepts developed within the NI framework may also be exported to other aspects of the SEEA-EEA framework, notably for ecosystem services. Thematic indicators focusing on particular services can be developed within the NI framework, simply by aggregating all indicators referring to a given service. Such measure of ecosystem service may be fairly rough however, and it may be desirable that specific measures of given services are developed freely, outside of any constraints, following a specific and adapted methodology. Once these have been obtained though, the question of aggregation across services still remains, and this can be achieved by converting these different measures into indicators, with associated reference values, that can be documented for each relevant LCEUs and EAUs within the NI framework. In this way changes in ecosystem condition may be compared with changes in ecosystem services and vice versa, as conceptualized in the Tables 2.3 and 2.4 in the SEEA-EEA handbook. It might also be possible to discuss how today's or earlier ecosystem management practices have changed the ecosystem condition and how this has affected the service provision capacity.