Technical Recommendations

in support of the System of Environmental-Economic Accounting 2012

Experimental Ecosystem Accounting

United Nations

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Technical Recommendations in support of the System of Environmental-Economic Accounting 2012— Experimental Ecosystem Accounting

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Preface

The *System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting* (SEEA EEA) constitutes a coherent framework for integrating measures emanating from ecosystems and their flows of services with measures emanating from economic and other human activities. Complementing—and building on—accounting for environmental assets, ecosystem accounting identifies the range of ecosystem assets within the environmental landscape (including forests, wetlands and agricultural areas) and articulates the connections between these assets and the economic and other human activities carried out in that landscape. Indeed, the explicit recognition by SEEA EEA of the role of place in this regard represents the first step on the pathway towards a meaningful understanding of the environmental-economic relationship. Moreover, the integration of ecosystem and economic information is intended to mainstream information on ecosystems within decision-making.

SEEA EEA was welcomed by the United Nations Statistical Commission at its forty-fourth session in 2013 as an important first step in the development of a statistical framework for ecosystem accounting. The Commission also encouraged its use by international and regional agencies, and countries wishing to test and experiment in this new area of statistics.

Following the endorsement of SEEA EEA, many countries began testing and experimentation at the national level, as well as subnationally (e.g., in individual administrative areas such as provinces, protected areas, cities and environmental areas, such as catchments). The growing demand for information on SEEA EEA demonstrates that this tool has proved to be a useful means of informing policies focusing on ecosystems.

Testing and experimentation have led to: (a) advances in thinking with regard to the measurement of ecosystems and their integration into an accounting framework; and (b) increased demand for practical recommendations on how to implement the accounting framework set out in SEEA EEA. The present *Technical Recommendations in Support of the System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting* are being issued in response to this demand. The *Technical Recommendations* complement SEEA EEA by presenting updates and extensions of ecosystem accounting-related concepts, methods and structures, and providing the desired practical guidance on its implementation. Some concepts and definitions (e.g., the definition of "ecosystem unit") have been substantially refined, and fundamental ecological principles have been incorporated in the accounting concepts and methods. Those principles govern the function and structure of the ecosystem as the key points of entry into the process of defining and classifying ecosystem assets and services. Inevitably, some of the issues raised could not be resolved within the time frame allocated for the publication of the *Technical Recommendations*; those issues have therefore been included in the research and testing agenda.

The evolution of the recommendations has revealed not only that substantive progress has been achieved in the development of ecosystem accounting-related concepts and methods but also that interest in this area is already significant—and broadening. The roll-out of the recommendations—in particular as a platform for a further forging of partnerships among the members of the many stakeholder communities—provides an opportunity to build momentum towards the recognition of the relevance of natural capital to decision-making in the public and private sectors.

The *Technical Recommendations* have been designed to serve as an intermediate step in the transition from the 2012 SEEA EEA to its revision, which is scheduled for completion in 2021. The aim of participants in the SEEA EEA revision process is to develop agreed concepts, methods and classifications for ecosystem accounting and a standard common language capable of supporting discussion and decision-making. The process will leverage the advances being made in the areas of geospatial information, including earth observation data, and other sources of big data as a means of supporting efforts to establish the standardized definitions and classifications required by ecosystem accounting. Further, the recognized need for information and indicators to support the monitoring of progress towards sustainability objectives, such as the Sustainable Development Goals and the goals under the post-2020 biodiversity framework, offers yet another clear motivation for refining SEEA EEA and defining internationally comparable indicators.

The *Technical Recommendations* were developed under the auspices of the United Nations Committee of Experts on Environmental-Economic Accounting and, in particular, through the oversight of its Technical Committee on SEEA EEA. The development process entailed two rounds of broad consultations, in December 2015 and March 2017, and benefited from review by and input from a large number of experts across many disciplines. The recommendations were developed as part of the Advancing Natural Capital Accounting (ANCA) project, jointly implemented by the Statistics Division of the Department of Economic and Social Affairs of the United Nations, United Nations Environment Programme and the Secretariat of the Convention on Biological Diversity, and funded by the Norwegian Agency for Development Cooperation.

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Abbreviations and acronyms

BSU	basic spatial unit
EA	ecosystem asset
EAA	ecosystem accounting area
EE-IOT	environmentally extended input-output tables
ENCA-QSP	Ecosystem Natural Capital Accounts Quick Start Package
ET	ecosystem type
FAO	Food and Agriculture Organization of the United Nations
FEGS-CS	Final Ecosystem Goods and Services Classification System
GDP	gross domestic product
GIS	geographic information system
IMF	International Monetary Fund
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
KIP-INCA	Knowledge Innovation Project on an Integrated System for Natural Capital and Ecosystem Services Accounting in the European Union
MAES	Mapping and Assessment of Ecosystems and their Services
MODIS	Moderate Resolution Imaging Spectroradiometer (algorithm)
NESCS	National Ecosystem Services Classification System (United States of America)
NPV	net present value
NSO	national statistical office
OECD	Organization for Economic Cooperation and Development
SEEA	System of Environmental-Economic Accounting
SEEA EEA	System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting
SEEA-AFF	System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries
SNA	System of National Accounts
SWAT	Soil and Water Assessment Tool
TEEB	The Economics of Ecosystems and Biodiversity
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UN-GGIM	United Nations Committee of Experts on Global Geospatial Information Management
USLE	universal soil loss equation
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
2008 SNA	System of National Accounts 2008

Chapter I
Introduction

1.1. Overview of ecosystem accounting

1.1.1. Nature of the *Technical Recommendations in support of the System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting*

1.1. The *Technical Recommendations in Support of the System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting* (referred to hereinafter as the "*Technical Recommendations*") cover a broad range of subject areas. Its aim is to provide support to ecosystem accounting-related testing and research. Since the drafting of the *System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting* (SEEA EEA) (United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organization for Economic Cooperation and Development and World Bank Group, 2014), there has been extensive further discussion and testing of concepts and engagement with a wider range of relevant experts. While the core conceptual framework remains robust, additional issues, interpretations and approaches have emerged, which are explored in section 1.3 below. The discussion of advances on specific topics in this rapidly developing field is designed to ensure that the content of the *Technical Recommendations* is as up to date as possible.

1.2. The *Technical Recommendations* also examine a wide range of data sources and methods that are relevant to the compilation of the various components of the ecosystem accounts. Addressing the evidence to date which indicates that different approaches to compilation are possible, the *Technical Recommendations* focus on the current state of play and the different pathways.

1.3. Ecosystem accounting is a relatively new field where the pace of advances is likely to continue to be rapid, given the scope of the testing under way. In consequence, the *Technical Recommendations* are to be viewed not as providing the final word on the subject but rather as the summing up of a stocktake of our understanding of ecosystem accounting at this stage of its development.

1.4. SEEA EEA is scheduled to be updated by 2020 through a formal process that has already commenced, after being endorsed by the United Nations Committee of Experts on Environmental-Economic Accounting at its twelfth meeting, held in New York from 19 to 21 June 2017. The aim of that process, which will take advantage of all relevant conceptual and practical developments, is to put in place the first international statistical standard for ecosystem accounting. To that end, the active participation of the statistical, research and academic communities involved in ecosystem-related measurement and analysis work is welcomed.

1.1.2. Conceptual motivation for ecosystem accounting

1.5. Ecosystem accounting constitutes a coherent framework for integrating measures of ecosystems and the flows of services arising from them with measures of economic and other human activity. Ecosystem accounting complements and builds on the accounting for environmental assets as described in the *System of Environmental-Economic Accounting 2012 Central Framework* (SEEA Central Framework) (United Nations, European Commission, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organization for Economic Cooperation and Development and World Bank, 2014). In SEEA Central Framework, environmental assets are accounted for as individual resources such as timber resources, soil resources and water resources. In contrast, the ecosystem accounting approach, as described in SEEA EEA, recognizes that these individual resources function in combination within a broader system.

1.6. The prime motivation for the development of ecosystem accounting stems from the perception that separate analyses of ecosystems and the economy do not adequately reflect the fundamental relationship between humans and the environment. In that context, the SEEA EEA framework provides a common platform for the integration of: (a) ecosystem assets-related information (i.e., on ecosystem extent, ecosystem condition, ecosystem services and ecosystem capacity); and (b) existing accounting information on economic and other human activity dependent upon ecosystems and the associated beneficiaries (households, businesses and governments).

1.7. The integration of ecosystem and economic information is intended to mainstream information on ecosystems in decision-making. Consequently, that information must exhibit a strong degree of relevance to current issues of concern. As described in SEEA EEA, the ecosystem accounting framework is intended for application at the national level, to enable the linking of information on a multiplicity of ecosystem types and services with macro-level economic information (e.g., measures of national income, production, consumption and wealth).

1.8. On the other hand, since the initial release of SEEA EEA, application of that framework has proved relevant at regional and subnational levels, encompassing, for example, individual administrative areas such as provinces, protected areas, cities and environmentally defined areas such as water catchments. Indeed, at those subnational levels, the potential of ecosystem accounting can be demonstrated more easily through direct linkage to the development of responses to specific policy themes or issues. In that regard, a subnational focus may be of particular interest in the development of pilot studies on ecosystem accounting, as facilitated by the increasing availability of data on ecosystems at a detailed level.

1.9. Significantly, using a common accounting framework for the measurement and organization of data at subnational levels supports the development of a more complete picture at the national level. Along the same lines, a broader picture of the dynamics of ecosystems at the transboundary and global levels can be achieved through coordination of the measurement and organization of ecological information on a smaller scale. Overall, the coordination and integration of data from various sources using an accounting framework can provide a rich information base for both local and broad-scale ecosystem and natural resource management.

1.10. The essence of ecosystem accounting lies in the partitioning of the biophysical environment into areas representing ecosystem assets. Potential ecosystem assets include forests, wetlands, agricultural areas, rivers and coral reefs. While the focus to date has been on accounting for land areas, including inland waters, ecosystem accounting has also been applied to coastal and marine areas.[1] Each ecosystem asset

[1] For applications to marine areas, see sect. 3.7.

is then accounted for in a manner analogous to the treatment of produced assets, such as buildings and machines, in the *System of National Accounts 2008* (2008 SNA) (European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and World Bank, 2009), which constitutes the international statistical standard for the compilation of national economic accounts.[2] That implies that ecological information pertaining to ecosystems can be recorded on the basis of the same measurement framework that is used to record information on produced and other economic assets. Thus, the stock and change in stock of each asset are recorded as a combination of: (a) balance-sheet entries at points in time; and (b) changes in assets through, for example, investment or depreciation and degradation.

1.11. Each ecosystem asset supplies a stream of ecosystem services. For produced assets, the services provided are known as capital services (e.g., housing services provided by a dwelling). The flows of services in any period (for both ecosystem assets and produced assets) are related to the productive capacity of the asset. Those services, which generate an income flow for the economic unit that owns or manages the asset, are also inputs to the production of other goods and services. The applications of that accounting model remain fundamentally consistent throughout the present *Technical Recommendations*. Box 1.1 provides additional introductory material on defining stocks and flows within an accounting context.

[2] As developed by economists Robert Solow and Dale Jorgenson, among others, in the 1950s and 1960s and applied actively in national accounting from the 1990s (see Organization for Economic Cooperation and Development, 2009).

Box 1.1
Recording stocks and flows for accounting

The terms "stocks" and "flows" are commonly used in discussions on measurement, but the applications of those terms can be different from the applications called for within an accounting context. For accounting purposes, stocks are the underlying assets that support production and the generation of income. Information concerning stocks may be recorded in physical terms (e.g., hectares of plantation forest) and in monetary terms. Stocks are generally measured at the beginning and at the end of each accounting period (e.g., the end of the financial year) and a balance sheet for each point in time is created through the aggregation of those measurements. For ecosystem accounting, the stocks of primary focus are the ecosystem assets delineated within the area in scope of the accounts. Conceptually, information on each ecosystem asset—for example, on its extent, condition and monetary value—can be recorded at the beginning and end of each accounting period and can thus contribute to understanding the stock's potential to support the generation of ecosystem services into the future (ecosystem capacity).

Two types of flows are recorded in accounting, namely, changes in stocks and flows related to production, consumption and income. Changes in stock include: (a) additions to stock as a result of investment or, in the case of ecosystem assets, natural growth and improvements in condition; and (b) reductions in stock due to extraction, degradation or natural loss.

Production, consumption and income are all flow-related concepts. For ecosystem accounting, the relevant flows of production, consumption and income relate to the supply and use of ecosystem services as generated by ecosystem assets and provided to beneficiaries, including businesses, governments and households. Benefits as described in ecosystem accounting are also flows of that type.

It is important that the two types of flows be clearly differentiated, since they should not be aggregated. A common incorrect treatment in accounting entails considering improvements in the condition of ecosystem assets to be flows that can be combined with flows of ecosystem services. The appropriate treatment entails considering that improvements in condition increase the capacity of the ecosystem asset to generate ecosystem services. In accounting, the various types of flows require distinct interpretations.

The distinction between stocks and the two types of flows, as described in the present publication, provides a basis for understanding the relationship between the maintenance and degradation of ecosystem assets on the one hand, and the supply of ecosystem services on the other. The information gathered within the accounting framework on both dynamics supports the analysis of ecosystem capacity and sustainability in a manner that is aligned with standard economic and financial analysis.

1.12. The accounting framework presented in SEEA EEA supports, complements and extends other ecosystem and biodiversity measurement initiatives in four important ways:

- First, the SEEA EEA framework encompasses accounting for ecosystem assets in terms of both ecosystem condition and ecosystem services. Often, measurement of ecosystem asset condition and measurement of ecosystem services are undertaken in separate fields of research. Hence, there are relatively few studies in which ecosystem assets and services are conceptualized as comprehensively as here.[3]
- Second, the SEEA EEA framework encompasses accounting in both biophysical terms (e.g., hectares, tons) and monetary terms using various valuation techniques.
- Third, the SEEA EEA framework is designed to facilitate comparison and integration with the economic data prepared in accordance with the System of National Accounts (SNA). That leads to the adoption of certain measurement boundaries and valuation concepts which are not systematically applied in other forms of ecosystem measurement. The use of SNA-derived measurement principles and concepts facilitates the mainstreaming of ecosystem information in standard measures of income, production and wealth.
- Fourth, the general intent of the SEEA EEA framework is to provide a broad, cross-cutting perspective on ecosystems at a country or comprehensive subnational level. However, as many ecosystem measurements are conducted at a detailed local level, the SEEA EEA framework is structured in such a way as to enable detailed data, once placed in context, to be utilized to produce a richly textured picture of the condition of ecosystems and the services that they supply.

[3] One area of work is the measurement of inclusive wealth (United Nations University—International Human Dimension Programme on Global Environmental Change and United Nations Environment Programme, 2014) where the incorporation of natural capital in broader measures of national wealth uses a framing that is very similar to the national accounts framing explored here.

1.1.3. Central measurement objective of ecosystem accounting

1.13. SEEA EEA is a result of work that was initiated by the international community of official statisticians, particularly the national accounts community. That work was directed towards the development of SEEA Central Framework. Ecosystems, including the need to account for their degradation, have long been a focus of interest within the context of environmental-economic accounting. However, the national accounting-based approach described in SEEA EEA only emerged in recent years, as official statisticians worked to synthesize the findings contained in the substantial literature on ecosystems and ecosystem services.

1.14. The facets of the conceptual framework are elaborated at greater length in the succeeding chapters. At the introductory level, however, there is a need to articulate the broad logic that serves as armature for a national accounting-based approach to compiling ecosystem accounts. That logic, which is referred to here as the central measurement objective, accounts for the breadth envisaged for ecosystem accounting, and underpins the approach to the organization of information and the potential applications. The components of the central measurement objective are as follows:

1.15. *Spatial structure and ecosystem assets.* What is referred to as the ecosystem accounting area, for example, a country or a region within a country, defines the scope of the set of ecosystem accounts. The ecosystem accounting area is considered to comprise multiple ecosystem assets, generally represented in accounts in terms of the homogeneous areas of different ecosystem types such as forests, lakes, deserts, agricultural areas and wetlands. While the total area being accounted for generally remains stable, the configuration of ecosystem assets and types, in terms of their area, alters over time through natural and land-use changes. For accounting purposes, where the delineation of assets is based on mapping mutually exclusive ecosystem asset boundaries, each ecosystem asset is considered a separable asset. Ecosystem extent accounts record the compositional changes within an ecosystem accounting area, including information on various ecosystem assets, which are usually grouped in such a way as to summarize the various ecosystem types.

1.16. *Ecosystem condition*. Each ecosystem asset also changes in condition over time. An ecosystem condition account for each ecosystem asset is structured to record the condition at specific points in time and the changes in condition over time. Those changes may be due to natural factors or human/economic intervention. Ecosystem accounting strives to enable the changes in condition of multiple ecosystem assets within a country or subnational region.

1.17. The measurement of ecosystems often overlaps with the measurement of biodiversity. In the ecosystem accounting framework, biodiversity is considered a key component in the measurement of ecosystem assets rather than an ecosystem service in its own right. That treatment aligns with accounting practice, in which a distinction is made between: (a) the assets that underpin production, which can improve or degrade over time; and (b) the production and income that is generated from the asset base.

1.18. *Supply of ecosystem services.* Ecosystem assets supply ecosystem services, either separately or in combination. The major focus at this time is on the supply of ecosystem services (i.e., provisioning, regulating and cultural services) to economic units, including businesses and households. They are considered final ecosystem services. The ecosystem accounting framework also supports the recording of flows of intermediate ecosystem services, which are flows of services between ecosystem assets. Recording those flows supports an understanding of the dependencies among ecosystem assets, for example, within a water catchment.

1.19. For accounting purposes, it is assumed that it is possible to attribute the supply of ecosystem services to individual ecosystem assets (e.g., timber from a forest) or, where the supply of services is more complex, to estimate a contribution from each ecosystem asset to the total supply.

1.20. *Basket of ecosystem services.* Generally, each ecosystem asset supplies a basket of various ecosystem services. Conceptually speaking, the intent in accounting is to record the supply of all ecosystem services over an accounting period for each ecosystem asset within an ecosystem accounting area.

1.21. *Use of ecosystem services*. For each recorded supply of ecosystem services, there must be a corresponding use. The attribution of the use of final ecosystem services to different economic units is a fundamental element of accounting. In SEEA EEA, the measurement boundary for final ecosystem services is defined so as to support integration of data with the production of goods and services that is currently recorded in the standard national accounts. The full and non-overlapping integration of measures of the supply of ecosystem services and the production of standard or traditional goods and services is a key feature of the SEEA EEA approach. Depending on the ecosystem service, the user (e.g., a household, business or Government) may receive that service while it is located either in the supplying ecosystem asset (e.g., when it is catching fish from a lake) or elsewhere (e.g., when it is receiving air filtration services from a neighbouring forest).

1.22. *Linking to benefits*. Flows of ecosystem services are distinguished from flows of benefits. The term "benefits", as used in SEEA EEA, encompasses: (a) SNA benefits, that is, the products (goods and services) produced by economic units as recorded in the standard national accounts; and (b) the non-SNA benefits that are generated by ecosystems and consumed directly by individuals and societies. As defined in SEEA EEA, benefits are not equivalent to the well-being or welfare that is influenced by their consumption or use. The measurement of well-being is not the focus of ecosystem accounting, although the data that are integrated through the ecosystem accounting framework can support such measurement directly.

1.23. *Valuation concepts*. The ambitious aim of integration with standard economic accounting data entails the derivation of estimates in monetary terms, which requires the use of a valuation concept that is aligned to the SNA. Using a common valuation concept enables the derivation of, for example, measures of gross domestic product (GDP) adjusted for ecosystem degradation, extended measures of production and consumption, and the estimation of extended measures of national wealth. The core valuation concept applied in the SNA and used in ecosystem accounting as well is exchange value, that is, the value of the service at the point of interaction between the supplier (the ecosystem asset) and the user.

1.24. *Valuation of ecosystem services and assets*. Each individual instance of supply and use of ecosystem services is considered a transaction for accounting purposes. In physical terms, each transaction is considered to be revealed in the sense that its recording reflects an actual exchange or interaction between economic units and ecosystem assets (including, for example, the appreciation of nature generated by the exploration of ecosystems). Yet, although the transaction is revealed, in most circumstances an associated value is not revealed because markets and related institutional arrangements for ecosystem services have not been established. The range of techniques that have been developed for the valuation of non-market transactions can be applied for the purpose of providing estimates of the value of the supply and use of ecosystem services in monetary terms. However, it should be noted that there exists a range of challenges with respect to implementation of those techniques and interpretation of the values that they yield.[4]

1.25. On the basis of the estimates of ecosystem services in monetary terms, the value of the underlying ecosystem assets can be estimated using net present value (NPV) techniques whereby the value of the asset is estimated as the discounted stream of income arising from the supply of a basket of ecosystem services that is attributable to an asset. Ideally, observed market values would be used for ecosystem assets such

4 For some ecosystem services, mainly provisioning services such as for food and fibre, the value of supply and use can be estimated directly at an aggregate level through utilization of information on associated economic transactions.

as agricultural land. However, it is likely that those market values will not incorporate the full basket of ecosystem services supplied or reflect values that are influenced by factors other than the supply of ecosystem services, for example, potential alternative uses of land.

1.26. The valuation approaches adopted for ecosystem accounting exclude the value of any consumer surplus that may be associated with transactions in ecosystem services. Also, the focus is on valuation in monetary terms, with no explicit incorporation of non-monetary valuation approaches. Consequently, the core monetary ecosystem accounts does not provide all of the information needed to support decision-making in every context. Nonetheless, the broad information set represented by the ecosystem accounts, in particular accounts in physical terms, provides, at a minimum, a coherent framework for decision-making in all situations.

1.27. Ultimately, meeting the central measurement objective requires a substantive collaboration in terms of skills and data. The present *Technical Recommendations* provide guidance on pathways that can be pursued and on the application of approaches that are undergoing active testing and implementation at national and subnational levels.

1.1.4. Measurement pathways

1.28. The national accounts framing of ecosystem measurement underpins the discussion that follows. It is clear, however, that differing motivations and rationales, reflecting other concepts and measurement boundaries, could be used for the measurement of ecosystems, particularly for the valuation of ecosystem services and ecosystem assets. Notwithstanding the differences in motivation and rationale, experience to date suggests that the types of information required for all of ecosystem measurement are for the most part either common or complementary. Much, therefore, is to be gained through ongoing discussion and joint research and testing.

1.29. Even within the framing by national accounting of ecosystem measurement, there are several alternative measurement pathways, that is, several different means through which the relevant data and accounts may be compiled. SEEA EEA, like SEEA Central Framework and the 2008 SNA, does not focus on how measurement should be undertaken or the appropriate sources and methods, but rather on what variables should be measured and the relationships among them. However, since the recommendations are intended to support compilation, the goal here is to establish approaches to measurement. At the same time, the *Technical Recommendations* cannot be viewed as a "cookbook", which specifies the precise quantities of the ingredients required to compile a set of ecosystem accounts. It is expected that continued testing and development of ecosystem accounting will yield advice that is more concrete.

1.30. The various approaches to compiling ecosystem accounts are best thought of as located along a spectrum. At one end are the "fully spatial" approaches that entail detailed spatial modelling and articulation of ecosystem assets and ecosystem service flows. At the other end are the "minimum spatial" approaches that seek to provide a broad overview of trends in key ecosystem types and services. In practice, the approach to ecosystem accounting that is being adopted lies between those two extremes, with the degree of spatial detail utilized being dependent on: (a) the type of research question being investigated; and (b) the availability of data and the resources for compilation; hence, the approach may change over time. An overview of those approaches is provided in paragraphs 1.31 to 1.37 below.

1.31. *Minimum spatial approach*. The minimum spatial measurement approach incorporates a more traditional perspective, that is, a perspective of the aggregate national accounting type. The aim of that approach, which is commonly undertaken at a national level or at the level of a large subnational region, is to provide a broad context of support for discussions and decisions on the use of environmental assets and ecosystems. To that end, the starting point is commonly identification of: (a) a specific basket of ecosystem services that are considered most likely to be supplied by ecosystems; and (b) a limited number of ecosystem types (perhaps about 10), for example, forests, agricultural land, coastal areas. Flows of each ecosystem service, attributed to ecosystem type where set, are then measured and, if relevant for decision-making, pertinent values can be estimated in order that measures of the monetary value of ecosystem services and assets may be derived.

1.32. The key feature of a minimum spatial approach is the absence of any requirement for a strict or complete spatial delineation of individual ecosystem assets; hence, the relationship between ecosystem services and ecosystem assets can be less precise. For example, estimates of timber provisioning services can be made using data on national timber production and resource rent valuation methods without attribution of those service flows to individual forest areas or types of forest.

1.33. Minimum spatial approaches may be less resource-intensive than fully spatial approaches but, at the same time, are unable to provide the information needed to analyse the detailed implications of policy options, since the characterizations of ecosystem assets are generally coarse (i.e., they use a limited number of ecosystem types) and need not be spatially specific. Thus, it is the relative size (area) of an ecosystem type, as distinct from an ecosystem asset's relative importance in overall ecosystem functioning, that will often heavily influence an ecosystem assessment. For example, recognizing the role of wetlands or linear features of the landscape, which are usually relatively small in terms of area, may be more difficult. Nonetheless, use of the minimum spatial approach not only offers a first glimpse of the potential of ecosystem accounting but also provides an information base that can be expanded through the addition of more detail up over time.

1.34. *Fully spatial approaches*. Fully spatial approaches generally reflect a more ecologically oriented perspective. Their starting point entails distinguishing among ecosystem assets at a fine spatial level. The aim is to delineate, through the use of classifications of ecosystem types, a relatively large number of mutually exclusive ecosystem assets (for example, using more than 100 ecosystem types) with a particular focus on their configuration in the landscape. The mapping of ecosystem assets and the services that they supply is an exercise that is particularly relevant in fully spatial approaches. The measurement of ecosystem services is generally more nuanced than in minimum spatial approaches, with supply being directly attributed to specific ecosystem assets, and estimates often taking into account spatial configuration in the application of biophysical models (including, for example, the proximity of ecosystem assets to local populations of people). The valuation of ecosystem services is a distinct step undertaken following the estimation of flows of ecosystem services in quantitative terms.

1.35. Generally, a fully spatial approach will be more resource intensive than minimum spatial types and, in that regard, implementation will require greater ecological and geospatial expertise, since the use of much higher levels of ecosystem-specific information would be expected. That approach increases the potential of ecosystem accounting to provide information that is highly relevant in assessing site-specific trade-offs and heightens the potential of the ecosystem accounting framework to assist in organizing a large amount of existing ecological data. On the other hand, such an approach raises challenges of data quality and aggregation that must be overcome if broader accounting narratives are to be created.

1.36. As previously noted, from a measurement perspective, the key difference between the minimum and fully spatial approaches lies in the extent to which the information underpinning the accounts is integrated on the basis of a coordinated spatial data system. Conceptually speaking, as the ecosystem accounting framework is spatially based, the aim in measurement should be, ideally, to adopt approaches that are more spatial in nature. Consequently, the *Technical Recommendations* are oriented towards descriptions that are spatially oriented, which includes support for the development of national spatial data infrastructure and associated investments in additional spatial data sets.

1.37. However, whether the entry point for measurement is a minimum spatial or a fully spatial approach, there is conceptual alignment, since the different approaches represent only different means of tackling the measurement challenge.[5] At the same time, it is not to be expected that each approach will provide the same estimates for a given region or country. In that context, by providing a standard set of definitions and measurement boundaries, the ecosystem accounting framework serves as a platform for comparing the results derived from different measurement approaches and, over time, for building a richly textured, comprehensive and coherent picture of ecosystems. Thus, notwithstanding the potential for flexibility in the choice of measurement approaches, comparison of measurements in different locations and over time can be carried out, provided the same accounting definitions are applied and the classifications used are consistent.

[5] Within the context of standard national accounts compilation, the relationship between these two approaches may be compared with that between the estimation of GDP using supply and use tables with associated product and industry details and its estimation through measurement of factor incomes and final expenditures. While these two approaches to GDP measurement are aligned conceptually, in practice they yield different estimates and support different policy and analytical uses.

1.1.5. Uses and applications of ecosystem accounting

1.38. Ecosystem accounts provide several important pieces of information in support of policy and decision-making related to the environment and the management of natural resources, reflecting the fact that the management of those resources is of relevance in economic, planning, development and social policy contexts.

1.39. *Detailed spatial information on ecosystem services supply*. Ecosystem services supply accounts provide information on the quantity and location of the supply of ecosystem services, which in turn provides insight into the wide range of services that are offered primarily, albeit not only, by natural and semi-natural vegetation. That information is vital to monitoring progress towards reaching policy goals such as achievement of a sustainable use of ecosystem assets and prevention of further loss of biodiversity. Definition and quantification of ecosystem services and the factors that support or undermine them are needed to highlight the importance of all types of ecosystems. Protection of the natural environment is highly important not just because of its potentially incalculable intrinsic value, but also because of the services that provide clear economic benefits to businesses, Governments and households. Information on that topic is also highly relevant for land-use planning and the planning of infrastructure projects, among others. For example, the potential impacts exerted by a road's possible locations on the overall supply of ecosystem services can be easily observed.

1.40. *Monitoring the status of ecosystem assets*. The set of ecosystem accounts provide detailed information on changes in ecosystem assets. The condition account uses a set of physical indicators to reveal the status of those assets. The monetary accounts provide an aggregated indicator of ecosystem asset values. Although that indicator does not set forth the "total economic value" of ecosystems, it does suggest the value of their contribution through the measurement, with exchange values, of the production and consumption of the ecosystem services included in the accounts. The overall value may be a less relevant indicator than changes in this value with regard to assessing overall developments in support of decision-making.

1.41. *Highlighting the ecosystem assets, ecosystem types and ecosystem services of concern to policymakers*. The accounts, when implemented over multiple years, clearly identify the specific ecosystem assets, ecosystem types (e.g., wetlands, coral reefs) and ecosystem services (e.g., pollination, water retention) that are changing most significantly. In the case of negative trends, the accounts would thus provide the information needed to determine priorities for policy interventions. Since information on several causes of ecosystem change (e.g., changes in land cover, changes in nutrient loads, fragmentation) are also incorporated in the accounts, there are baseline data through which to identify relevant areas of focus for effective policy responses.

1.42. *Monitoring the status of biodiversity and indicating specific areas or facets of biodiversity under threat*. As compared with existing biodiversity monitoring systems, the accounting approach offers the scope, when biodiversity accounts are included, to provide regularly updated information on biodiversity in a structured and coherent manner. Aggregated indicators for administrative units, including for countries and at the continental scale (e.g., the scale of Europe), provide information on trends in biodiversity as well as on species and habitats of particular concern. In that context, the biodiversity account can include information on species important for ecosystem functioning (e.g., so-called keystone species, whose condition is indicative of environmental quality) and species whose presence and/or abundance is important for biodiversity conservation (e.g., rare, threatened or endemic species). Where biodiversity accounts are presented as maps of biodiversity indicators, specific areas of concern and improvement can be identified, as well as areas of particular importance for biodiversity conservation both inside and outside protected areas.

1.43. *Quick response to information needs*. In support of ongoing reporting requirements and discussion of emerging issues, the accounts provide information that is:

- Comprehensive, i.e., it encompasses a wide range of ecosystem types, services and assets; maps and tables; and physical and monetary indicators;
- Structured, i.e., it follows the SEEA international framework as aligned with the SNA;
- Coherent, i.e., it integrates a broad range of data sets in order to provide information on ecosystem services and assets;
- Spatially referenced, i.e., it links data to the scale of ecosystems and allows the integration of data across different accounts.

1.44. Accounts should be updated on a regular basis (ideally, annually), considering source data availability and user needs, so as to ensure that a structured, comprehensive and up-to-date database is available to respond to policy demands for specific information. An integrated assessment—for example, an environmental cost-benefit analysis of a proposed policy or an assessment of, say, new investment in infrastructure—can typically take anywhere from half a year to several years. In large part, policy demands reflect the need to collect information on the state of the environment in affected areas. Ecosystem accounts present a ready-to-use database that can significantly shorten the time needed to address that need. Assessment of specific policies or investments will likely require information additional to that presented in the ecosystem accounts; and in many cases, a wide range of environmental and economic impacts can be modelled through a combination of information included in the accounts and relevant additional data. Further, different assessments can be based on a common underlying information set, which allows for an increased focus on the outputs derived from policy reviews, rather than on evaluating the data inputs. A common core set of economic data underpins economic modelling in an analogous fashion.

1.45. *Monitoring the effectiveness of various policies*. By enabling changes in the status of ecosystems and the services they provide over time to be tracked in a spatially explicit manner, the accounts serve as an important tool for monitoring the effectiveness of various regional and environmental policies. The spatial detail of the accounts allows comparison of developments between areas influenced by policies and areas experiencing less or no influence of specific policy decisions. In particular, the concept of return on investment may be applied by assessing the extent to which expenditure on a specific programme or a particular piece of regulation has exerted a material impact on the condition of relevant ecosystems or the flows of ecosystem services.

1.46. *Use in economic and financial decision-making*. Ecosystem accounting is designed to support the use of environmental information in standard economic and financial decision-making. In that context, the measurement of the value of ecosystem services in exchange values supports direct integration with standard financial and national economic accounting data. The data can in turn be used to extend standard economic modelling approaches and to enhance broad indicators of economic performance, such as national income, savings and productivity. While those measures and applications are different from the more common applications of valuations of ecosystem services, the prospect of being able to consider ecosystems through multiple analytical lenses is a strong motivating factor for pursuing the development of valuations for accounting purposes.

1.2. Scope of the *Technical Recommendations*

1.2.1. Connection to SEEA Central Framework

1.47. SEEA Central Framework provides a definition of environmental assets that encompasses the measurement of both individual environmental assets (such as land, soil, water and timber) and ecosystem assets. In many senses, ecosystem accounting reflects how individual assets and resources function together. Consequently, there are often strong connections between accounting for individual environmental assets, as described in SEEA Central Framework, and measures of ecosystem assets and ecosystem services. Perhaps the key difference in measurement scope lies in the fact that the number of ecosystem services that are included in SEEA EEA is much larger than the number included in SEEA Central Framework. That is to say, while SEEA Central Framework incorporates measurements related to provisioning services, such as flows of timber, fish and water resources, SEEA EEA extends the Framework's scope so as to include regulating and cultural services.

1.48. There are therefore important advantages for ecosystem accounting stemming from the use of the range of materials that have been developed related to the measurement of water resources, including the *System of Environmental-Economic Accounting for Water* (SEEA-Water) (United Nations, 2012b); agriculture, forests and timber, fisheries, *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries* (Food and Agriculture Organization of the United Nations and Statistics Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2016); and land. While those materials have generally not been developed for ecosystem accounting purposes, they support the development of relevant estimates and accounts, especially in relation to methods and data sources.

Also, those publications describe potential applications of accounting, which can be a useful focus for compilers.

1.49. The individual environmental asset accounting described in SEEA Central Framework could be adapted to two areas identified in SEEA EEA, accounting for carbon and accounting for biodiversity. The emerging range of materials in those two areas of measurement can also be used to support the measurement of ecosystem assets and ecosystem services.

1.50. The potential to apply information on accounting for land, water, carbon and biodiversity is described in more detail in chapter IX, entitled "Thematic accounts". Significantly, the compilation of accounts for these specific asset types are not only of straightforward use in compiling ecosystem accounts but are directly applicable in specific policy and analytical situations.

1.2.2. Connection to other ecosystem accounting and similar materials

1.51. The *Technical Recommendations* have incorporated the findings presented in a range of other technical materials on ecosystem accounting, as developed from 2013 to 2015,[6] and have also striven to synthesize, as effectively as possible, the learning and experiences gathered from the increasing number of projects and initiatives on ecosystem accounting. Those materials, projects and initiatives, which were developed by different agencies in different contexts, have been a source of assistance in the testing of SEEA EEA through their laying out of technical options and communication of the potential of a national accounting approach to ecosystem measurement. A short, non-exhaustive summary of the various projects and initiatives is provided in annex II. Research papers and journal articles on ecosystem accounting, which continue to be released, are referred to throughout this publication.

6 These include *Ecosystem Natural Capital Accounts: A Quick Start Package* (ENCA-QSP) (Weber, 2014a); the *Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States* (United Nations Environment Programme, 2014); the working paper entitled "Designing pilots for ecosystem accounting" (Wealth Accounting and the Valuation of Ecosystem Services (WAVES), 2014); and *Mapping and Assessment of Ecosystems and their Services: An Analytical Framework for Ecosystem Assessments under Action 5 of the EU Biodiversity Strategy to 2020* (MAES) (Second report) (Maes and others, 2013).

1.2.3. Audiences for the *Technical Recommendations*

1.52. The primary audiences for the *Technical Recommendations* are: (a) people who work on compilation and testing for ecosystem accounting and related areas of environmental-economic accounting; and (b) people—possibly affiliated with separately established ecosystem and biodiversity monitoring and assessment programmes—who provide data for those compilation and testing exercises. Ecosystem accounting, being a multidisciplinary exercise, requires the integration of data from multiple sources. Testing therefore entails arrangements for the participation of a range of agencies, including, at a minimum, national statistical offices, environmental agencies and scientific institutions.

1.53. While the *Technical Recommendations* are intended to be accessible to people across a spectrum of disciplinary backgrounds, it is understood that levels of understanding of the different facets of the ecosystem accounting model vary. For example, it is likely that those with a background in or familiarity with national or corporate accounting will find the concepts and approaches presented here to be more accessible. For those without such a background, insights into key features of the national accounting-based approach to measurement, which underpins the ecosystem accounting model, are provided in annex I.

1.54. The *Technical Recommendations* should also assist those who use the information that emerges from sets of ecosystem accounts by elucidating the broad ecosystem accounting model, the relevant definitions and terms, and the types of approaches to measurement. However, potential applications of ecosystem accounts and possible tools for analysis using ecosystem accounting are not the focus of this publication. As a starting point for consideration of such applications, readers are directed to the document that resulted from the first Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Policy Forum, held in The Hague in November 2016 (WAVES, 2017).

1.2.4. Implementation of ecosystem accounting

1.55. By its very nature, ecosystem accounting is an interdisciplinary undertaking, with each discipline, including statistics, economics, national accounts, ecology, hydrology, biodiversity and geography, contributing its own perspective and language. In order for the benefits to be obtained from an integrated approach, institutional coordination and cooperation are required to support the compilation and use of accounting-based solutions. The compilation of ecosystem accounts requires not only the creation of teams with the appropriate mix of skills but also the building of networks of established experts based in different institutions to ensure that the best information and techniques relevant to a particular country or region can be accessed. In addition, the broader development and implementation of ecosystem accounting requires the establishment of networks and arrangements comprising policymakers, decision makers, local communities and other stakeholders. Given the need for a large number of stakeholders with a variety of skills, there are ample opportunities for those working in all areas of measurement and policy to participate in ecosystem accounting projects.

1.56. It will likely be possible to use results and findings from past and ongoing projects on environmental and ecosystem measurement to inform current work on ecosystem accounting. Generally, there are strong overlaps of information requirements between different projects, notwithstanding differences in purpose and analytical intent. Indeed, it is likely that advancements in ecosystem accounting can support the organization of information required for other projects focused on analysing the connections between the environment and economic and human activity.

1.57. An important aspect of implementation, given the need for the involvement of experts in many areas, is the allocation of resources to coordination, data sharing and communication. Thus, the task of implementation is not solely a technical measurement-related challenge: appropriate institutional arrangements and resourcing to support ongoing engagement and communication are also required.

1.58. One particular motivation for seeking the participation of non-accounting and non-statistical experts in ecosystem accounting projects lies in the fact that the implementation of ecosystem accounting is intended to include the establishment of ongoing measurement programmes. That is different from the undertaking, as is common in environmental assessments, of one-off or short-term studies of specific areas or environmental themes. Those long-term ambitions, paralleling the ongoing measurement of GDP and economic statistics, suggest that engagement with relevant experts must also become ongoing, which would afford the opportunity to strengthen and improve measurement over time and to contribute to the compilation of enduring data sets. In turn, these data sets should underpin further research and analysis, which, ideally, would generate a virtuous circle of strengthened information supply.

1.59. The process of development of SEEA has been led by the official statistics community. Thus, while implementation will require the participation of representatives of many different agencies and disciplines, there are several areas of ecosystem accounting that warrant the involvement of national statistical offices. The roles of those offices are elaborated in box 1.2.

Box 1.2
Potential roles of national statistical offices in ecosystem accounting

There are roles commonly played by all national statistical offices, which suggests that there is a place for national statistical offices in the development of ecosystem accounting under a variety of possible institutional arrangements. The lead agencies in ecosystem accounting-related testing and research are encouraged to utilize the expertise of NSOs in these areas. It should be emphasized that:

- As organizations that work with various large data sets, NSOs are well placed to contribute their expertise to the collection and organization of data from a range of different sources.
- In the area of ecosystem accounting, there are many examples of different definitions of similar concepts and there are known to be multiple classifications of ecosystem services and ecosystem types. As a core function of NSOs is to establish and maintain consistent definitions, concepts and classifications, the involvement of NSOs in this area of work would be beneficial.
- NSOs have the capability to integrate data from various sources so as to construct coherent illustrations of relevant issues and themes. Most commonly, NSOs focus on constructing coherent pictures based on socioeconomic information and can extend this capability to encompass environmental information.
- NSOs work within broad national and international frameworks of data quality that enable a consistent and complete assessment and accreditation of various information sources and the associated methodologies.

With their national coverage, NSOs play a relatively unique role in creating a picture of socioeconomic conditions at national level. Ecosystem accounting could benefit substantially from consideration of how standard statistical techniques for scaling information to national level may be applied, particularly with respect to geospatial statistics.

- The voice of NSOs can be an authoritative one by virtue of their application of standard measurement approaches and data quality frameworks and their particularly unique role within government.

1.60. The actual role that a national statistical office might play depends on the scope of the activities in which it has traditionally been involved. For example, some offices may be characterized as having a strong tradition of working with geographical and spatial data, while others have a history of engagement in development and research. National statistical offices with those types of experience could play a leading role in the development of ecosystem accounting, although offices without such experience could still play an important role.

1.61. Agencies other than national statistical offices play an important role in ecosystem accounting. Of particular note are those agencies that are leaders in work on geographical and spatial data (see para. 1.60), particularly the mapping of environmental data and the use of remote sensing information, including for spatial and temporal modelling of ecosystem services. Overall, the primary lesson to be derived from the emerging work on ecosystem accounting is that collaborative approaches are essential to measurement of progress in this field.

1.62. The SEEA implementation guide (United Nations, 2013) provides general advice on how to establish programmes of work for the implementation of SEEA and highlights the various tools that have been developed to guide compilers on the relevant steps. As the number of ecosystem accounting projects grows, compilers are also encouraged to learn from experiences in other countries and regions. The websites of the FAO/Statistics Division System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries, the Statistics Division, the World Bank-led WAVES partnership, and related websites provide links to relevant reports.

1.3. Incorporation of SEEA EEA conceptual improvements in the *Technical Recommendations*

1.3.1. Introduction

1.63. The *Technical Recommendations* build directly upon the conceptual framework for ecosystem accounting described in SEEA EEA. For the most part, they provide additional explanations and directions related to compilation. However, there are some areas where reinterpretation or clarification of the conceptual model has been required as a result of the discussions on ecosystem accounting that have been ongoing since the completion of the SEEA EEA drafting process in 2013. There are five main areas in which conceptual improvements have been introduced.

1.3.2. Treatment of spatial units

1.64. There are several ways in which the *Technical Recommendations* have clarified and advanced the treatment of spatial units for ecosystem accounting (see chap. III for details, in particular figure 3.1). In summary, the overall scope of the ecosystem accounts is determined by the boundary of the ecosystem accounting area, formerly referred to as the ecosystem accounting unit. Individual ecosystem assets, formerly referred to as land-cover/ecosystem functional units (LCEUs), are delineated within the ecosystem accounting area. The ecosystem assets now clearly serve as the conceptual underpinning of ecosystem accounting and delineate the area that supplies ecosystem services, which, jointly with human inputs, result in benefits from the ecosystem to society.

1.65. The *Technical Recommendations* clarify the fact that the delineation of ecosystem assets involves, ideally, the use of a range of ecological and non-ecological factors, including vegetation type, soil type, hydrologic conditions and land management practices. Those criteria can be used to classify ecosystem assets to various ecosystem types. Generally, ecosystem accounts are compiled and presented for areas of the same ecosystem types rather than for individual ecosystem assets (e.g., for forests as a whole rather than for each forest).

1.66. While the *Technical Recommendations* retain the use by SEEA EEA of basic spatial units, they now specify that the basic spatial unit may be formed in various ways, including through the use of a reference grid or through the delineation of polygons. That flexible approach to defining the basic spatial unit reflects the fact that in ecosystem accounting work, the basic spatial unit is a component of measurement rather than a conceptual underpinning of that work.

1.3.3. Account labelling and structure

1.67. With regard to the range of accounts included in SEEA EEA, upon reflection, it was determined that the structure and naming conventions needed further development. As described in chapter II, the *Technical Recommendations* incorporate three key advances:

- A distinction has been drawn between ecosystem accounts and thematic accounts. Ecosystem accounts specifically cover stocks and changes in stocks of ecosystem assets, and flows of ecosystem services, and may be compiled in both physical and monetary terms. Thematic accounts cover particular topics, including land, carbon, water and biodiversity. Data from thematic accounts may be used in compiling ecosystem accounts and in support of analysis of ecosystem accounting information and may also provide important contextual information in their own right.

- Some of the ecosystem accounts have been relabelled: for example, the ecosystem asset account, in monetary terms, is now referred to as the ecosystem monetary asset account.
- In terms of account structures, all but one are similar to those presented in SEEA EEA. The exception is the supply and use account for ecosystem services, which now has a more articulated structure, achieved through building upon the physical supply and use tables of SEEA Central Framework.

1.3.4. Measurement of ecosystem services

1.68. In SEEA EEA, the ecosystem accounting focus was clearly the measurement of the contribution of final ecosystem services to the generation of benefits. Two aspects of that focus have been clarified in the *Technical Recommendations*.

1.69. First, there is a clearer explanation in the *Technical Recommendations* of the way in which the incorporation of final ecosystem services in the accounting framework reflects an extension of the production boundary compared with the production boundary as defined in the SNA, which underpins the measurement of GDP. Thus, in a national accounting context, the integration of final ecosystem services leads to an expansion of the measures of output.

1.70. That expansion of the production boundary has a range of implications for the application of national accounting principles. In terms of effects on currently defined GDP, there are two cases to be considered. Where ecosystem services contribute to benefits that are included currently as goods and services within the SNA production boundary (SNA benefits), there is no impact on GDP (value added) because the output of ecosystem services is offset by a recorded input to the production of those SNA benefits. However, where the ecosystem services contribute to goods and services outside the SNA production boundary (non-SNA benefits), there is a direct increase in the level of GDP. Overall, it is expected that the extension of the production boundary will broaden measures of production, consumption and income and hence the associated value of assets that supply the services. Table 8.1 offers a stylized illustration of these results in numerical terms.

1.71. Second, there is a clearer recognition in the *Technical Recommendations* of the potential for recording intermediate ecosystem services, which, in accounting terms, reflect the flow of services between ecosystem assets. All ecosystem services, final and intermediate, can be related to ecosystem processes. A sole focus on final services facilitates a recognition of the important role that those processes play in directly supporting economic and human activity. The recording of intermediate services in the accounting framework supports a better conceptualization of the connections and dependencies subsisting among ecosystem assets. That illustrates the potential of ecosystem accounting to delineate the contributions of all ecosystems and associated ecosystem processes wherever they are located and to foster an understanding of the possible impacts of economic production and consumption on ecosystem assets.

1.72. At the same time, there is a practical reality to be considered, namely, the very large number of intermediate ecosystem service flows that might be recorded. Consequently, it is not anticipated that, at this stage, there would be a focus on measuring those flows. However, depending on priorities with respect to the compilation of the accounts, intermediate services related to particular policy questions—for instance, nursery services provided by coral reefs upon which the supply of fish for harvest in the open oceans depends—may be estimated and recorded within the accounting framework. Further, given the challenges of measuring intermediate services directly, it should be noted that information on those services may be recorded in ecosystem extent and condition accounts. Accounting for intermediate ecosystem services therefore remains in the SEEA EEA research agenda.

1.3.5. Ecosystem condition

1.73. The concept of ecosystem condition in the *Technical Recommendations* remains identical to that formulated in SEEA EEA. However, as it was determined, upon reflection, that there was a need to enhance the measurement of condition, the *Technical Recommendations* have framed the issue in a broader context. The framing includes the notion of top-down and bottom-up approaches to measurement; a recognition of the fact that some indicators of condition may be related to fixed characteristics as distinct from variable ones; and significant clarification on the subject of measuring condition from small to larger scales. With regard to scale, a continuum is described that extends from the definition of indicators for individual characteristics for a single ecosystem type, to the definition of indicators that are potentially comparable across ecosystem types with multiple characteristics.

1.74. The *Technical Recommendations* recognize more explicitly than SEEA EEA that the measurement of condition depends on the current pattern of land use and land management and the associated mix of ecosystem services. That is likely, in turn, to affect how ecosystem units are delineated.

1.3.6. Ecosystem capacity

1.75. In SEEA EEA, ecosystem capacity is mentioned but not defined. While the development of SEEA EEA revealed the relevance of the concept, no agreement could be reached on how it might be best described within an accounting context. Since the release of that publication, it has become increasingly clear that the concept of ecosystem capacity, which links the concepts of ecosystem condition and ecosystem services, is in fact fundamental within an accounting context. Most importantly, the concept of ecosystem capacity can be directly linked to the measurement of ecosystem degradation, itself a fundamental variable in national accounting.

1.76. The *Technical Recommendations* therefore provide a more thorough description of the concept of ecosystem capacity than does SEEA EEA, and from both a biophysical and a monetary perspective. An expanded definition is proposed and some of the associated measurement issues are examined. As demonstrated in chapter VII, where the major part of the discussion of ecosystem capacity is found, any discussion of the subject requires the integration of measures of ecosystem extent, condition and services. As yet, no final position has been taken on the definition of that concept and related measurement and research are continuing.

1.4. Structure of the *Technical Recommendations*

1.77. All aspects of ecosystem accounting as discussed in SEEA EEA fall within the scope of the *Technical Recommendations*. The discussion of the subject presented here is structured as follows:

- Chapter II introduces the ecosystem accounting framework and the ecosystem accounts, and describes approaches to measurement;
- Chapter III provides an overview of the spatial areas used in ecosystem accounting and the compilation of ecosystem extent accounts;
- Chapter IV focuses on the measurement of ecosystem condition;
- Chapter V introduces the subject of accounting for the flows of ecosystem services, including a description of the ecosystem services supply and use account, a discussion of some of the key boundary- and classification-related issues, and consideration of possible approaches to measurement;
- Chapter VI examines the subject of valuation of ecosystem services in monetary terms;
- Chapter VII considers accounting for ecosystem assets in monetary terms and its relationship to measures of ecosystem capacity and degradation;
- Chapter VIII updates the discussion in chapter VI of SEEA EEA on the integration of ecosystem and economic information using the accounting framework;
- Chapter IX provides an introduction to various thematic accounts related to ecosystems, namely, accounts for land, carbon, water and biodiversity.

Chapter II
Ecosystem accounts and approaches to measurement

Key points

- The core SEEA EEA ecosystem accounting framework provides a robust means of placing information on ecosystem assets, ecosystem services, the benefits generated from ecosystem services and well-being in context.
- There are five core ecosystem accounts: the ecosystem extent account, the ecosystem condition account, the ecosystem services supply and use accounts in physical and monetary terms, and the ecosystem monetary asset account.
- The accounting structures presented in the *Technical Recommendations* can be adapted to support varying levels of detail in terms of the number of ecosystem types and ecosystem services and at different spatial scales.
- There is no single measurement path that must be followed in the compilation of ecosystem accounts. Most commonly, differences in measurement reflect differences in the level of spatial detail in the compilation of accounts, which depends on the approach used, running from fully spatial to minimum spatial. The choice of approach reflects differences in data availability and the type of analytical or policy question that is of primary interest.
- There are five broad compilation-related steps within ecosystem accounting. Each step provides useful information for analytical and policy purposes. As a general observation, the initial focus is on measurement in physical terms followed by valuation in monetary terms, although in some cases, initial measurement in monetary terms is possible.
- Ideally, physical measures of ecosystem extent and condition, and measures of the supply and use of ecosystem services should be compiled concurrently, since there will be a close relationship between (a) the selection of indicators used to measure ecosystem condition and (b) the use of the ecosystem, as reflected in the basket of ecosystem services and the characteristics of the users.
- It is likely that the development of a set of accounts will require an iterative approach that entails the progressive development of individual accounts and work then directed towards ensuring coherence and consistency among them.
- An ecosystem accounting approach is most useful when accounts are compiled on an ongoing basis so that a time series of coherent information can be analysed and relationships and trends can be established.

2.1. Introduction

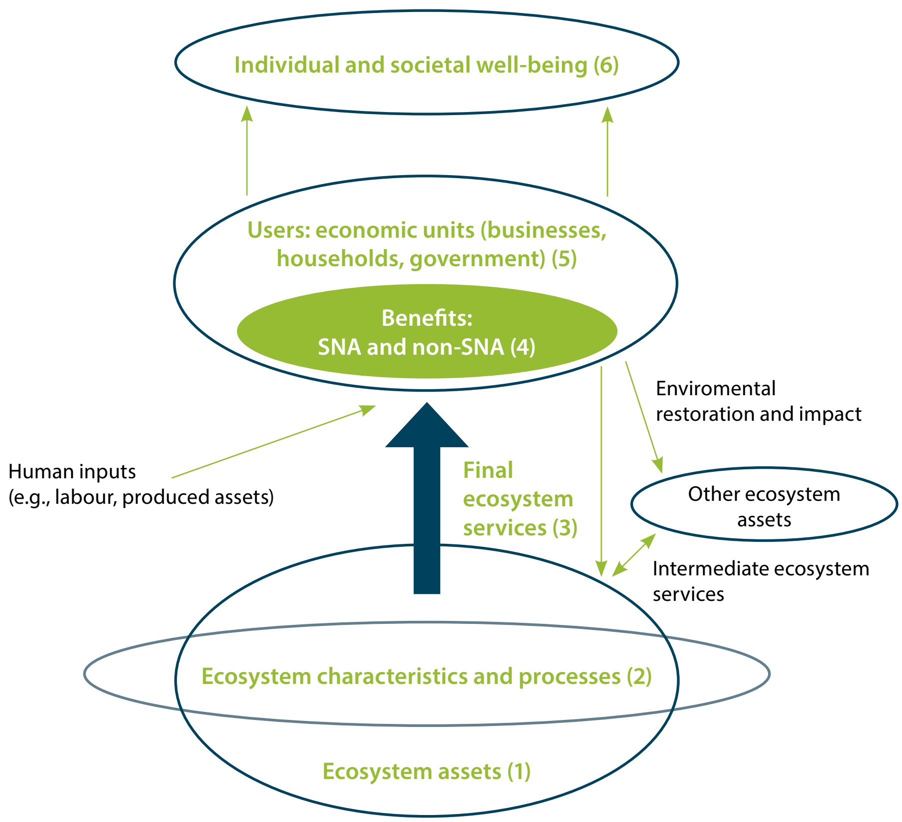
2.1. The present chapter is an overview of ecosystem accounting; the chapters that follow provide relevant details. The chapter's descriptions of key elements of the ecosystem accounting framework and discussion of ongoing developments in the field complement and build upon the content of chapter II.

2.2. SEEA EEA ecosystem accounting framework

2.2. SEEA EEA ecosystem accounting framework has five main components, which are set out schematically in figure 2.1. At the bottom of the figure, the focus of the framework is the various biotic and abiotic components within an **ecosystem asset (1)**, which is defined by a spatial area.[7] The delineation of that area is required for accounting purposes and should be considered a statistical representation of an ecosystem, even if by nature they are not discrete systems that align with strict spatial boundaries. Different types of ecosystem assets exist within a territory (e.g., forests, wetlands), and those need to be distinguished. Approaches to the delineation of spatial areas for ecosystem accounting are described in chapter III.

7 Some components may be accounted for individually (e.g., in accounts for timber, water and soil) using the asset accounting guidelines in the SEEA Central Framework.

Figure 2.1
The ecosystem accounting framework



Source: Adapted from SEEA EEA (United Nations, European Commission, FAO, OECD and World Bank, 2014), figure 2.2.

2.3. Each ecosystem asset possesses a range of relevant **ecosystem characteristics and processes (2)** which together form the basis for the functioning of the ecosystem. While each ecosystem asset is uniquely defined, ecosystem processes generally operate both within and across individual ecosystem assets. Thus, while in figure 2.1 ecosystem assets are represented as discrete areas, the associated ecosystem processes are considered to be unbounded and hence extend beyond the asset boundaries.

2.4. The accounting framework proposes that the stock and changes in stock of ecosystem assets be measured by assessing the relevant ecosystem asset's **extent and**

condition through the use of indicators of that asset's area and characteristics. The extent and condition of an ecosystem asset is affected by not only natural changes, but also human activity in the landscape. While each ecosystem asset is considered separable for accounting purposes, there are connections with **other ecosystem assets** reflecting both the movement of water, energy and materials, and flows of intermediate ecosystem services (such as pollination services). The measurement of ecosystem extent is described in chapter III and the measurement of ecosystem condition in chapter IV.

2.5. Each ecosystem asset generates a set or basket of **final ecosystem services (3)**, which are defined as contributions to the production of benefits. Final ecosystem services encompass a wide range of services provided to economic units (i.e., businesses, governments and households) and may be grouped into provisioning services (i.e., those related to the supply of food, fibre, fuel and water); regulating services (i.e., those related to activities of filtration, purification, regulation and maintenance of air, water, soil, habitat and climate); and cultural services (i.e., those related to the activities of individuals in, or associated with, nature).

2.6. **Benefits (4)** may be *SNA benefits*: goods or services (products) produced by economic units (e.g., food, water, clothing, shelter, recreation) currently included in the economic production boundary of the SNA; or *non-SNA benefits*: benefits that accrue to individuals, or society generally, which are not produced by economic units (e.g., clean air). By convention, the measurement scope of non-SNA benefits for ecosystem accounting purposes is limited to the flow of ecosystem services with a direct link to human well-being.

2.7. In the accounting system, for each supply of final ecosystem services, there is a corresponding use that leads to the production of either an SNA or non-SNA benefit. Further, in each sequence of use of ecosystem services and production of benefits there is an associated **user (5),** that is, an economic unit (business, government or household). Thus, every final ecosystem service flow represents an exchange between an ecosystem asset—as a producing-supplying unit in the accounting system—and an economic unit. Both SNA and non-SNA benefits contribute to **individual and societal well-being (6)**.

2.8. The measurement of ecosystem services in physical terms is described in chapter V and the valuation of ecosystem services in chapter VI. Ecosystem accounting does not focus on the measurement of individual or societal well-being. It is to be noted, however, that in some decision-making contexts, there may be direct interest in the assessment of well-being, which may then influence the choice of valuation approach. While the ecosystem accounts do not present valuations of well-being and welfare change, the ecosystem accounting framework provides information, particularly biophysical information, that is relevant to this form of analysis.

2.9. A key motivation for the development of ecosystem accounting is the desire to achieve an understanding of the potential of ecosystem assets to provide services into the future and hence contribute to sustainable overall individual and social well-being. In that context, the scientific literature on ecosystem accounting has proposed four concepts related to ecosystem services (Hein and others, 2016, building upon, inter alia, Bagstad and others, 2014; and Schröter and others, 2014): (a) the *actual flow* of ecosystem services, as recorded in the ecosystem services supply and use account; (b) the *capacity* of ecosystems to supply services, corresponding to the sustainable flow of services, subject to there being a demand for such services (flow equals capacity for regulating services); (c) the *potential supply* of services, indicating the potential sustainable flow of services, assuming that there is no limitations in the demand for the service (hence under this proposal, potential flow is a function of ecosystem characteristics only, that is, it is not influenced by the presence of people using the service); and (d) ecosystem *capability*, reflecting the ability of the ecosystem to generate services if it were managed differently. Potential supply and capability are concepts that are relevant for environmental management, albeit less so for accounting. Although it may be noted that condition accounts are linked most directly to the potential of the ecosystem to supply services rather than to the actual service supply, which also depends upon human use of the ecosystem. These concepts are further discussed in chapter VII.

2.10. Finally, the aggregate contribution and role of all ecosystem assets are relevant in understanding national-level changes in wealth and associated concepts of sustainability. The integration of information on ecosystem assets and services with data from the SNA accounts is described in chapter VIII.

2.3. Ecosystem accounts

2.3.1. Placing the ecosystem accounts in context

2.11. There are five core ecosystem accounts (see table 2.1). Depending on the measurement pathway that is pursued, which in turn will be linked to the intended application of the accounting information, there will be a greater or lesser focus, in compilation, on the various accounts. The options for measurement and the links to the different accounts are described later in this chapter.

Table 2.1
Core ecosystem accounts

1	Ecosystem extent account—physical terms
2	Ecosystem condition account—physical terms
3	Ecosystem services supply and use account— physical terms
4	Ecosystem services supply and use account—monetary terms
5	Ecosystem monetary asset account—monetary terms

2.12. The five accounts constitute an accounting system that presents a comprehensive and coherent view of ecosystems.[8] At the same time, each account has merit in its own right and does not rely on other accounts to invest it with meaning. Further, since the accounting principles that underpin the accounts are derived from the SNA, the data from the ecosystem accounts can be directly related to the set of economic accounts that encompass the measurement of national income and institutional sector and national wealth. Indeed, it is possible to compile accounts that integrate ecosystem and economic accounts (see chap. VIII).

8 Hence, there is not one single all-encompassing ecosystem account.

2.13. In serving as the basis for the integration of ecosystem data with the economic accounts of the SNA, SEEA EEA framework incorporates a range of measurement choices, particularly with regard to the scope of ecosystem services and the concepts used for valuation. It would be possible to design ecosystem accounts that complement to those described here by adopting, for example, different valuation concepts to accord with particular policy and analytical purposes, while still applying the same basic accounting framework in figure 2.1. While such complementary accounts are not discussed here, they could be an area for further research.

2.14. As noted in section 2.2, ecosystem assets have a range of biotic and abiotic components—for example, timber resources, water resources, land and soil resources—

which are directly covered by environmental-economic accounting. The various accounts for individual components can provide information that contributes directly to the measurement of ecosystem assets and ecosystem services, as well as information that is useful in a stand-alone context. In the context of ecosystem accounting, they are called thematic accounts. Accounts for four themes—namely, land, water, carbon and biodiversity—are discussed in chapter IX, which also takes note of other themes for which accounts may be compiled.

2.15. A common feature of the measurement approaches described in this chapter is their utilization in the situation in which the ecosystem accounting framework is applied at national level within the context of multiple ecosystem assets (i.e., across the variety of ecosystem types within an ecosystem accounting area) and for multiple ecosystem services. That is analogous to the coverage of the national accounts, which includes the activities of all industries resident within a national economic territory.

2.16. It is recognized, however, that the application of the ecosystem accounting framework may also have a more tailored focus. For example, the framework may be applied for measurement of:

- A single ecosystem asset or ecosystem type (e.g., a forest or forests) and/or a single ecosystem service (e.g., water regulation). For individual provisioning services, there may be a direct connection to natural resource accounting, as described in chapter V of SEEA Central Framework (United Nations, European Commission, FAO, IMF, OECD and World Bank, 2014);
- A single ecosystem asset or ecosystem type and multiple ecosystem services. Accounting at this scale may be of interest in the management of specific ecosystems or ecosystem types (e.g., wetlands);
- Multiple ecosystem types and single ecosystem services. Accounting of that type may be of interest with regard to understanding the dynamics of supply of a specific service across a broad spatial area (e.g., water regulation, carbon sequestration);
- Areas of land within a country that have common land use or land management arrangements in place (e.g., national parks, protected areas).

2.17. The logic of the ecosystem accounting framework can be applied in all of these “reduced” or tailored cases. Moreover, to the extent that individual projects focus on these more-tailored accounts, it should be possible to integrate the findings within a broader project covering multiple ecosystem assets and services. Of course, the potential for integration is heavily dependent on the adoption by the various projects of consistent measurement boundaries and classifications, which would then become a prime motivation for application of a common ecosystem accounting framework.

2.18. Another application of ecosystem accounting with a tailored focus involves regions within a country, which may include accounts at subnational administrative levels or for well-defined ecological areas (e.g., water catchments). Further, accounts at a multi-country level (e.g., the level of all European Union countries) can be envisaged. In short, the ecosystem accounting framework can be applied at these different spatial levels.

2.19. In most instances, a staged approach to development of ecosystem accounts should be considered the most effective. Typically, an initial set of accounts including an ecosystem extent account, an ecosystem condition account and an ecosystem services supply and use account for a single year would be compiled. The duration of an initial development phase may be from one to two years. Depending on the initial scope, an expansion could involve developing accounts for a larger set of services and condition indicators, undertaking valuation of ecosystem services, compiling an ecosystem monetary asset account and developing a time series of accounts. This should be undertaken as an iterative process in which ongoing releases of accounting information would incorporate successive improvements in the accounts and underlying sources and methods. The rate of progress would depend on a range of factors including the availability of resources, the complexity of account design (e.g., the number of ecosystem types and ecosystem services), data availability, the degree of experience in conducting spatial analysis of ecosystems and ecosystem services, and the extent of the collaboration among relevant agencies that could be achieved.

2.3.2. Ecosystem extent accounts

2.20. The common starting point for all ecosystem accounting work will be the organization of information on the extent or area of different ecosystem types within a country, which is important for four reasons. First, defining the ecosystems of interest for accounting purposes is by no means a straightforward task and a balance will need to be struck among the following factors: scale of analysis, available data and policy questions. It would be highly appropriate for the discussion to focus initially on the definition of ecosystem assets and the delineation of their extent.

2.21. Second, the organization of the information required to establish an ecosystem extent account, which determines which ecosystem types will be used, will provide the basis for subsequent measurement of ecosystem condition and many ecosystem services, since indicators will generally vary by ecosystem type.

2.22. Third, the structure of the ecosystem extent account, as set out below in paragraph 2.23, shows that accounting entails the measurement of assets over time, in this case through the estimation of opening and closing balances for an accounting period.

2.23. Fourth, the ecosystem extent account provides not only a clear foundation for the development of the other ecosystem accounts but also information that is important in its own right. For example, when compiled at appropriate levels of detail, the ecosystem extent account provides: (a) a common basis for discussion among stakeholders of the composition of ecosystem types within a country and (b) an assessment of ecosystem diversity at a national level. Extent accounts can also support the derivation of indicators of deforestation, desertification, urbanization and other forms of land use-driven change.

2.24. The structure of the basic ecosystem extent account and relevant data sources are presented in chapter III.

2.3.3. Ecosystem condition accounts

2.25. A central feature of ecosystem accounting is its organization of biophysical information on the condition of different ecosystem assets across the area for which the ecosystem accounts are produced (the ecosystem accounting area (EAA)). The ecosystem condition account provides insight into how ecosystems within the EAA change, and how those changes may influence the flows of services supplied by those ecosystems. A variety of indicators for selected characteristics are used for the compilation of the ecosystem condition account in physical terms. The structure of the ecosystem condition account is described in chapter IV.

2.26. Generally speaking, it will be relevant to compile condition accounts by ecosystem type within the EAA, since each ecosystem type (e.g., forests, grasslands, wetlands, etc.) has distinct characteristics that should be taken into account when assessing condition. The measurement approach also recognizes that much information on ecosystem condition is available by ecosystem type rather than by specific ecosystem assets, although such data may also be available and should be utilized wherever possible.

2.3.4. Ecosystem services supply and use accounts

2.27. The supply of ecosystem services by ecosystem assets and the use of those services by economic units, including households, constitute one of the central features of ecosystem accounting. Those are the flows that reflect the link between ecosystem assets and economic and human activity. The supply and use account, which records the actual flows of ecosystem services supplied by ecosystem assets and used by economic units during an accounting period, may be compiled in both physical and monetary terms. An extensive discussion of the ecosystem services supply and use account is provided in chapter V.

2.3.5. Ecosystem monetary asset accounts

2.28. Asset accounts are designed to record information on stocks and changes in stocks (additions and reductions) of ecosystem assets. That includes accounting for ecosystem degradation. The ecosystem monetary asset account—which records that information in monetary terms, based on the valuation of ecosystem services and in connection with information on ecosystem extent and condition—is described in chapter VII.

2.3.6. Related accounts and concepts

2.29. The set of ecosystem accounts encompasses a complete coverage of accounting in both physical and monetary terms for all ecosystem assets and ecosystem services within a given ecosystem accounting area. However, those accounts, together with the information they contain, cannot be considered in isolation: two types of connection to other accounts need to be described.

2.30. The first type of connection entails the integration of ecosystem accounting information with the standard economic accounts, that is, the compilation of integrated ecosystem-economic accounts. The compilation of such accounts is relevant for the derivation of degradation-adjusted measurement of national income, and the measurement of national wealth in extended balance sheets, and with respect to support for the incorporation of ecosystem services into extended input-output and other economic models, and the measurement of other macroeconomic indicators, such as environmentally adjusted measurement of multifactor productivity. Issues associated with the compilation of integrated ecosystem-economic accounts are described in chapter VIII.

2.31. The second type of connection is to the various accounts of SEEA Central Framework and similarly structured accounts for carbon and species-level biodiversity.[9] The Central Framework accounts, like those for carbon and species-level biodiversity, focus on individual resources or flows such as water, timber, fish, soil and land. Since those individual components are present within ecosystems, from an accounting perspective, there must be consistency in terms of the picture presented between the individual or thematic accounts on the one hand and the ecosystem accounts on the other.

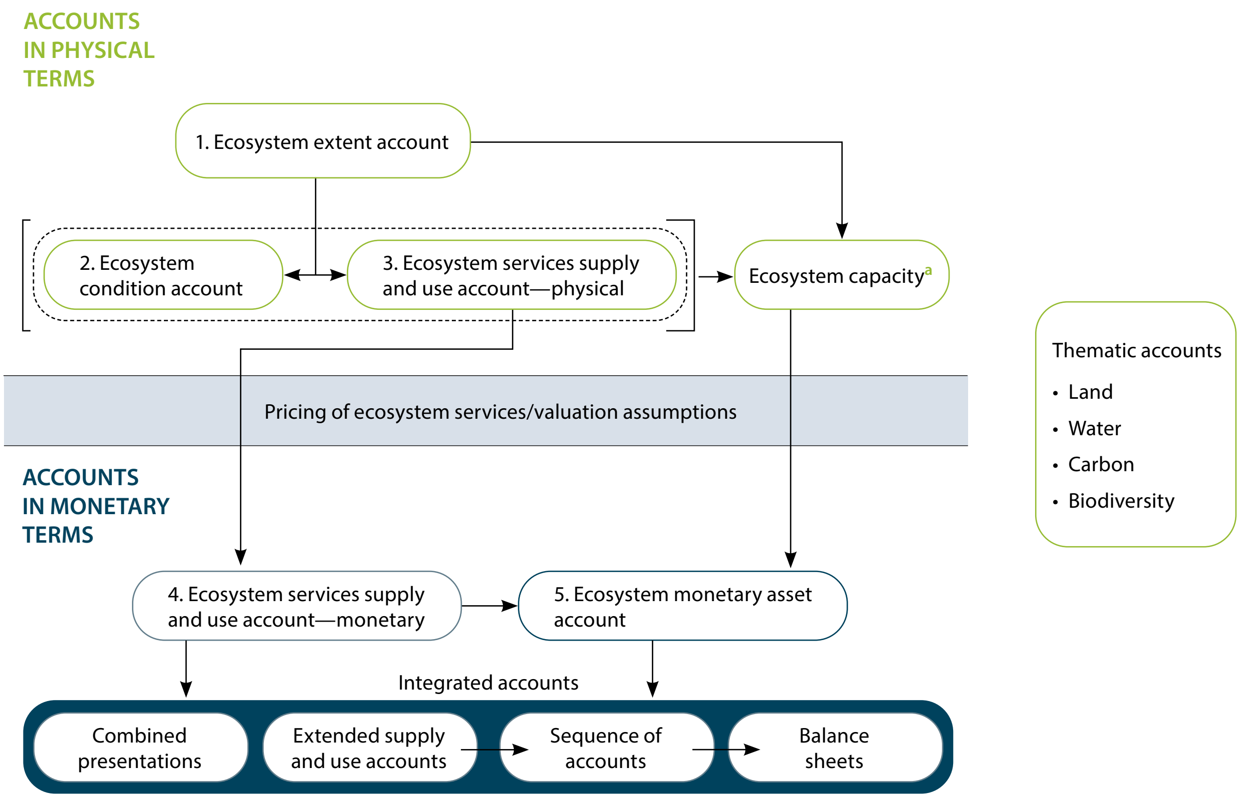
[9] Pursuant to the Convention on Biological Diversity (*United Nations Treaty Series*, vol. 1760, No. 30619), biodiversity can be considered in terms of genetic, species and ecosystem diversity. The assessment of ecosystem diversity is supported by the compilation of ecosystem extent accounts. Genetic diversity, however, has not been a focus of ecosystem accounting up to this point.

2.32. Four key thematic accounts—for land, water, carbon and species-level biodiversity—are described in chapter IX. Those accounts are of direct relevance in the compilation of ecosystem accounts, particularly with regard to supporting consistency in measurement across various ecosystem types, by providing, for example, a broad framework for the integration of information on stocks and flows of water resources. In addition, the information in each of the thematic accounts is likely to be of direct relevance in supporting discussion on specific policy themes, including land management and planning, water resource management, management of carbon stocks and greenhouse gas emissions, and biodiversity.

2.33. There is a need not only to develop these two types of accounting connections, but also to analyse and apply an important concept not reflected directly in the ecosystem accounts listed in paragraph 2.32 above, namely, ecosystem capacity. Ecosystem capacity reflects the ability of an ecosystem to sustainably generate an ecosystem service under certain assumptions (see sect. 7.3 for details). It underpins the measurement of the valuation of ecosystem assets, since the asset life of an ecosystem is directly related to changes in its capacity. In effect, the concept of capacity can serve as the basis for integrating measures of ecosystem condition, ecosystem services and ecosystem degradation. An account for ecosystem capacity has not yet been developed, but there are ongoing advances in conceptualizing ecosystem capacity, which are discussed in chapter VII.

2.34. The logic underpinning the connections between the various ecosystem accounts and those related accounts and concepts is articulated in figure 2.2. In the figure, the ecosystem extent account is shown to provide a starting point for compilation. The compilation of the ecosystem condition account and the compilation of the ecosystem services supply and use account are shown to be concurrent exercises (depicted using the dotted line), with the combination of information from those accounts feeding into the measurement of ecosystem capacity. However, there is no stand-alone ecosystem capacity account. The compilation of monetary supply and use accounts and asset accounts can be undertaken using relevant valuation techniques, with the information feeding into the compilation of integrated accounts. The thematic accounts are shown as providing information that supports the compilation of all ecosystem accounts. It is important to note that in practice, as described in the following section, there are different ways in which the compilation steps can be undertaken, which depend on the analytical and policy questions of focus and the data available.

Figure 2.2
Connections between ecosystem accounts and related accounts and concepts



[a] An account for ecosystem capacity has not been designed at this stage. The figure provides a conceptualization of where capacity measures would be situated.

2.4. Steps in the compilation of ecosystem accounts

2.4.1. Introduction

2.35. Ecosystem accounts can provide information that is relevant within a range of policy and analytical contexts. However, in the initial development and testing phase, it is likely necessary for the number of specific purposes for which ecosystem accounts might be compiled to be more limited. The type of policy question helps determine: (a) whether the scale of the accounts is to be subnational (at the level, e.g., of water catchment, province or habitat type) or national; and (b) the type of data needed. Over time, and building on the initial testing through progressive development, extension and integration, a more complete set of national-level ecosystem accounts can be envisaged. Further, the development of an initial set of ecosystem accounts is likely to spark an awareness of additional potential applications.

2.36. Determining the appropriate coverage and spatial detail for a set of ecosystem accounts, including the specific accounts to be compiled, must be made a subject of discussion among the institutions involved in the compilation process. It is also necessary to determine the relevant reference period or periods for the accounts. As multiple data sources need to be brought together for compilation of the accounts, the adoption of methods of adjusting data from various sources to a common reference period or periods is required.

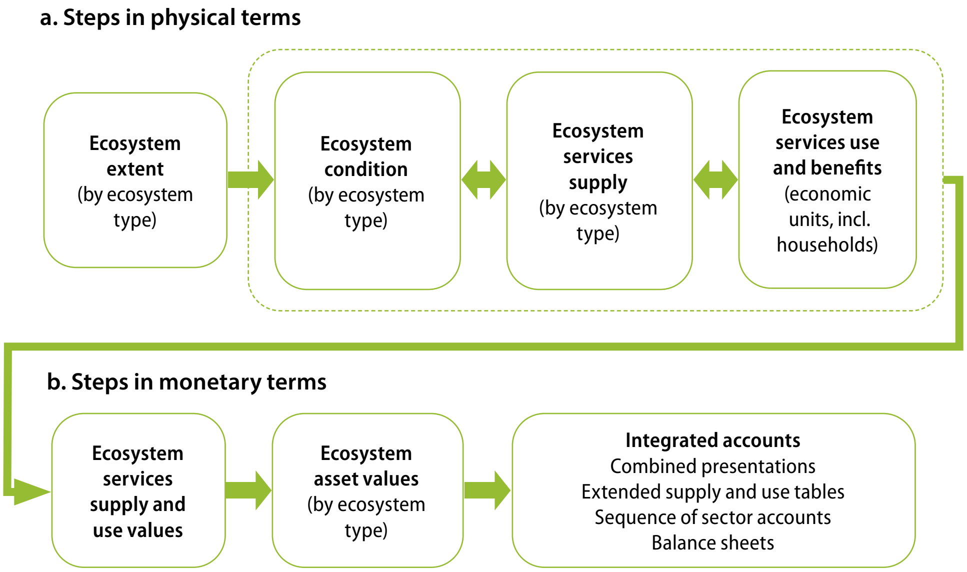
2.37. It is anticipated that the content of the *Technical Recommendations* will be able to support the discussion required to make those choices, with the understanding that other factors, such as the availability of resources, will also need to be taken into account. Following the general principles of SEEA implementation (see SEEA implementation guide), the discussions should involve all relevant stakeholders, including policymakers, data analysts, account compilers and source-data holders. Highly useful support could be provided for those discussions by the diagnostic tools that have been developed for such purposes.[10] Significant benefits could be derived as well from establishment of a senior-level steering committee and associated multi-stakeholder working or technical groups. It is to be noted that the information in the *Technical Recommendations* is appropriate for discussions on both the commencement of pilot studies and the establishment of national programmes of work.

2.38. The conceptual framework for ecosystem accounting presented in figure 2.1 illustrates, in general terms, the relationships between the different stocks and flows. The connections between the accounts displayed in figure 2.2 reflect the overall accounting picture. The present section provides an overview of the steps involved in compiling ecosystem accounts.

2.39. Those broad steps are displayed in figure 2.3. The first set of steps entails accounting in physical terms and the second set of steps, accounting in monetary terms. While it is useful to view that sequencing, the reality with respect to the accounting is that there are multiple iterations over the course of the accounting process and, further, that the precise starting point may vary. The aim of those iterations, which utilize multiple data sources, is to present a consistent picture. While ecosystem accounts are unlikely to convey the full richness and complexity of ecosystem relationships, they should provide: (a) a strong organizing framework for consideration of the information; and (b) the means of conveying the key messages for use in policy and analytical discussions.

10 See, for example, United Nations, Statistics Division, "Implementation and diagnostic tool", under the Project "Advancing the SEEA Experimental Ecosystem Accounting". Available at https://unstats.un.org/unsd/envaccounting/workshops/Mexcio_2015_eea/Session%2013%20-%20%20SEEA EEA%20-%20Diagnostic%20Tool%2029MAY15%20V3.pdf.

Figure 2.3
Broad steps in ecosystem accounting



Note: The dotted line surrounding the boxes for ecosystem condition, ecosystem services supply and ecosystem services use and benefits signifies that measurement of these concepts may often be completed concurrently, and iteration between them is appropriate in developing a single best picture. Also, while the figure portrays a progression from physical to monetary terms, for some provisioning services, direct estimation of monetary values may be undertaken, or estimates for the accounts may be taken from existing studies.

2.40. A primary question with regard to determining the approach to ecosystem accounting is whether to focus on more spatially detailed measurement or more aggregated, minimum spatial measurement. A detailed fully spatial approach is needed for a more comprehensive incorporation of ecological information, for example, concerning ecosystem condition and measurement of ecosystem services at detailed spatial levels. A minimum spatial approach is appropriate if the immediate objective is broad-scale assessment of ecosystem asset values in monetary terms and integrated measurement of national income and wealth. In practice, a combination of spatial and non-spatial measurement approaches is likely to be adopted, taking into account the relative data quality at different spatial scales.

2.41. The use of different spatial approaches is illustrated in table 2.2. The table demonstrates that a continuum extends from (a) the application of minimum spatial analysis whose goal is the production of aggregated accounts, to (b) a fully spatial approach directed towards the production of both accounting tables and accounting maps for all accounts produced. To adopt a fully spatial approach is to recognize that the purpose of compiling tables and maps is not only to facilitate presentation but also to provide compilers and analysts with insights relevant to evaluating the data and understanding relevant structures and trends.

2.42. A fully spatial approach has policy applications that are additional to those available with a minimum spatial approach, although not every possible application is listed in the table. It is important to recognize, however, that while the approaches are distinct, they utilize the same ecosystem accounting framework. Measurement-related differences will thus be attributable to differences associated with the availability and choice of data sources with differing levels of spatial detail, the need for and extent of modelling undertaken, and the assumptions underlying the derivation of aggregate measures.

Table 2.2
Spatial analysis in ecosystem accounting

Complexity of special analyses	Approach	Use of maps	Spatial resolution of data	Examples of policy applications (indicative, depending upon context)
	Fully spatial account	Maps to be produced for all ecosystem accounts for the complete ecosystem accounting area	All basic spatial units (BSUs) will be populated with data. Most of the data will be modelled and/or interpolated, some data will be downscaled. Data cannot be assumed to be accurate for every individual BSU but may present average values for a specific ecosystem type	Understanding how ecosystems support the economy; Monitoring changes in ecosystem capital over time and across space; Spatial and land-use planning; Comparing ecosystem changes in different areas (e.g., as a consequence of different areas or different policies); Supporting enviromental impact assessment and enviromental cost-benefit analysis.
	Partial spatial account	Maps to be produced only if necessary for the analysis of specific ecosystem extent, condition or services indicators	Data may be reported by spatial unit, administrative unit or ecosystem type, depending upon the indicators concerned	Understanding how ecosystems support the economy; Monitoring changes in ecosystem capital over time; Comparing ecosystem changes in different administrative units (e.g. as a consequence of different policies.)
	Minimum spatial account	No or very few maps produced	Data are produced for each administrative unit, without considering spatial heterogeneity within the units	Understanding how ecosystems support the economy; Monitoring changes in ecosystem capital over time.

2.43. The need for spatial analysis is also a function of the amount of information already available on ecosystem condition and ecosystem services from other sources. If there is, for example, a measurement system for ecosystem condition in place for an EAA, the decision may be taken to use that system rather than compile an alternative ecosystem condition account. Such a system is Norway's Nature Index (Certain and others, 2011), a comprehensive framework for measuring ecosystem condition, which considers the spatial distribution of species content in Norway. As the Nature Index provides an index value for species-level biodiversity for the country's smallest administrative unit, namely, the municipality, it constitutes a partial spatial approach.

2.4.2. Summary of the steps for compiling and developing the full set of accounts

2.44. The main steps of relevance along a spatial measurement pathway are described in paragraphs 2.45 to 2.53 below, within the context of the general considerations set forth in section 2.4.1. Where a minimum spatial approach has been adopted, it may be possible to prepare monetary accounts following the pathway displayed in figure 2.3b, commencing in step 4 (valuation of ecosystem services). However, in this case, information on the supply of regulating services in the EAA is required. This information cannot be derived from the national accounts or surveys and needs to be based upon spatial modelling studies. Estimates of the value of ecosystem assets (step 5) can in principle be obtained without compiling ecosystem extent and condition accounts, provided suitable assumptions are made regarding the likely changes in the physical characteristics of ecosystem assets (e.g., regarding the life of a fixed asset).

2.45. *Step 1:* Delineation of the area for which the accounts are compiled (the EAA) (the first important step in ecosystem accounting). The EAA may cover the entirety of a country's land area (including inland waters) and, as appropriate, relevant coastal and marine areas, possibly extending to a country's exclusive economic zone. Thought should also be given in this first phase to data infrastructure requirements; and the fact that a fully spatial approach will be more demanding in terms of computing capacity and data storage should be duly noted. This is discussed in chapter III, which also discusses the issues of delineating and classifying ecosystem assets for ecosystem accounting purposes.

2.46. Information on the area of an EAA can be presented in an **ecosystem extent account**, of which a key aim is to measure the change over time in the composition of ecosystem types within a country. The ecosystem extent account is described in chapter III, and the related land accounts are discussed in chapter IX.

2.47. *Step 2:* Compilation of the **ecosystem condition account** using the listing of ecosystem types determined for the ecosystem extent account. It is to be noted that this step may be undertaken following step 3 ((a) and (b)); in any event, as signified by the dotted line in figure 2.3, the measurement of ecosystem condition should take into consideration relevant flows of ecosystem services. Chapter IV discusses the compilation of ecosystem condition accounts in more detail. Chapter IX discusses the compilation of information on land, carbon, water and biodiversity using accounting approaches, a reflection of the fact that those data may be relevant in monitoring the condition of many ecosystems.

2.48. *Step 3:* Measurement of **ecosystem services in physical terms**.[11] The step is carried out by considering each ecosystem service in turn and determining the associated ecosystem types and appropriate indicators for understanding supply and use. This task should be conducted using a classification of ecosystem services, such as that described in chapter V, which could provide a checklist so as to ensure appropriate coverage.

2.49. One common way of thinking about the supply of ecosystem services, as reflected in figure 2.1, is to imagine that each ecosystem type produces a specific basket of services in the same way as a factory produces a set of outputs. That is certainly true for some ecosystem services, mainly provisioning services, in which materials are harvested or extracted from a given ecosystem asset (e.g., timber from a forest or water from a lake). However, for several types of ecosystem services, particularly regulating services, the benefits derived arise through the effective "collaboration" among different ecosystem types. For example, the regulation of water flows for the purpose of

[11] In this context, "physical" means "non-monetary". Measurement in physical terms encompasses ecosystem services that reflect flows of materials and energy, flows of services related to the regulation of an ecosystem, and flows related to cultural services (see SEEA EEA, para. 3.2).

providing flood protection includes contributions from forests, grasslands and other ecosystem types within a floodplain. While it is possible to estimate the contribution of different ecosystem types to the provision of an individual service (e.g., the relative contribution of forests to water regulation), the best starting point for measurement is likely to be an individual service rather than a single ecosystem type.

2.50. Step 3 should encompass estimation of both the supply of ecosystem services and the use of those services by various beneficiaries. The information on supply together with the information on use is utilized to compile an **ecosystem services supply and use account**. Grouping the beneficiaries in ecosystem accounting in the same way as in the economic accounts—that is, by industry group and by institutional sector—is a means of supporting integration with the national economic accounts. The possible approaches to measurement are discussed in chapter V.

2.51. *Step 4:* **Valuation of ecosystem services** in monetary terms. There are many examples of valuing of ecosystem services, which is a necessary step for certain types of integration with the standard national accounts, such as for adjusted GDP and extended measures of net wealth. The valuation of ecosystem services supports the compilation of the **ecosystem services supply and use account in monetary terms,** as well as the **ecosystem monetary asset account** and measures of ecosystem degradation. The measurement of ecosystem degradation requires an assessment of ecosystem capacity that reflects the connections between ecosystem condition, ecosystem extent and ecosystem services.[12] The valuation of ecosystem services is discussed in chapter VI, and the compilation of ecosystem monetary asset accounts and the estimation of ecosystem capacity is described in chapter VII.

2.52. *Step 5:* Use of information on ecosystem services, ecosystem assets and ecosystem degradation, as derived from the accounts described in Step 4, to integrate environmental and economic data and augment the current standard national accounts. As discussed in chapter VIII, that may be carried out in a number of ways, including through:

(a) Compilation of combined presentations in which data on ecosystem condition and services in physical terms are presented alongside standard economic data, such as on value added, employment or costs of environmental restoration;

(b) Full extension of the ecosystem services supply and use accounts in monetary terms to also include all products. That approach can be used to display the integration of ecological and economic supply chains;

(c) Compilation of an extended sequence of accounts in which standard economic measures such as GDP, national income and national saving are adjusted for the cost of ecosystem degradation. Adjusted measures may also be derived by the institutional sector and industry;

(d) Estimation of a national balance sheet in which the value of ecosystem assets is incorporated with the value of other assets and liabilities in order to derive extended measures of national wealth.

2.53. Undertaking those steps, under either fully spatial or minimum spatial approaches to measurement, should proceed with the understanding that the logic of the approaches is to be consistent with that of the types of approaches used for the compilation of national accounts. National accounting measurement exhibits some differences from many statistical and scientific measurement approaches, particularly concerning the integration and confrontation of data. The key aspects of national accounting approaches to measurement are summarized in annex I, which

[12] The measurement of ecosystem capacity may be facilitated by the description of baseline scenarios—that is, of expected changes in ecosystem condition given relevant business-as-usual assumptions.

has been included to provide an overview of the key elements of the national accounting approach that underpins the compilation of ecosystem accounts described here. This material is highly relevant to those who have not practised national accounting.

2.5. Key considerations in compiling ecosystem accounts

2.54. Six key considerations emerge in building an understanding of the set of ecosystem accounts as presented in the *Technical Recommendations*.

2.55. First, this system of accounts is designed, as far as possible, to enable information from different accounts to be readily compared. There is more than one account, and while each account can stand alone, relationships between the accounts can be highlighted by structuring the information appropriately, based on the recognition that, in practice, the connections between ecosystem service flows and ecosystem assets are difficult to define and measure.

2.56. Second, a highly specific design feature of the ecosystem accounts allows the information, ultimately, to be integrated with the standard national accounts that record economic activity. That design feature, which does not impact all accounts, is particularly relevant for accounts for ecosystem services and accounts compiled in monetary terms.

2.57. Third, the accounting structures presented should not be considered unchangeable with regard to their levels of detail. For example, the ecosystem condition accounts, described in detail in chapter IV, are structured according to broad ecosystem types (e.g., grasslands). In practice, however, it may be most relevant to provide a finer level of detail for some specific ecosystem types (e.g., level of type of grassland). Such rearrangements of information are perfectly appropriate and are usually necessary to ensure that the level of detail is determined based on analytical and policy requirements and with regard to data availability.

2.58. Fourth, the accounts described in the *Technical Recommendations* present information for one accounting period, usually one year, while accounting information is most commonly of interest for its presentation of time series of information, that is, for multiple accounting periods. It should be noted that the duration of an accounting period can be altered, for example, for the purpose of developing sub-annual accounts that may be relevant for such purposes as seasonal analysis of ecosystem services related to water.

2.59. Assuming that a time series of accounts is compiled, users of the accounting information are likely to require a reorganization of the information so that time can become one of the dimensions presented in the accounts. In practice, that is not a conceptual issue but rather one of data management and dissemination. Compilers should feel free to restructure the accounts described here to ensure that the resulting structure be the one that is best suited to the presentation and analysis of data, in the context of the associated policy questions and the needs of users.

2.60. Fifth, the structure of accounts generally displays a level of detail suitable for presentation and analysis of outputs from accounting, that is, the level of detail required for the application of accounting principles (e.g., regarding supply and use, or end-of-period stocks and changes in stocks). However, it is generally necessary for underlying information to be organized at different, usually lower, levels of aggregation before being entered into the accounts.

2.61. In the case of ecosystem accounting, for spatial approaches, it is likely ideal to compile data at an appropriately detailed level using a common spatial data infrastructure and then, for accounting purposes, to aggregate to the relevant ecosystem-type level. That does not require that ecosystem accounts be compiled at fine levels of detail but rather that the input (or source) data and the output (or disseminated) data[1]3 be managed separately. Indeed, making the distinction between input and output data is essential if changes to the source of the input data are to be managed effectively without affecting the integrity of the time series of data contained in the disseminated accounts. Making changes to input data, including changes to classifications, should be considered a normal and common practice in accounts compilation.

13 The term "reported data" is commonly used by most non-statisticians to signify output or disseminated data. However, for statisticians the term refers to collected or reported data used to produce statistical estimates. Given this divergence in meaning, the term is not used in the present *Technical Recommendations*.

2.62. Detailed spatial information is a feature of some input data, for example, remote sensing- and satellite-based data. However, for most other input data sources, the generation of detailed spatial data with coverage across relevant parts of the ecosystem accounting area requires additional work. For data sourced from official statistical sources, it is commonly necessary to downscale aggregate data using allocative techniques. The development of geo-referenced statistical information may be a useful input to this process. With regard to administrative data sources, while data may be available for specified subnational areas, adjustment may be needed to align data to ecosystem boundaries of interest. Again, geo-referencing of data is likely to be useful in this task.

2.63. For information on environmental stocks and flows, many input data are collected at specific locations, and the challenge for ecosystem accounting is to determine whether those data can be applied in other locations. In the valuation of ecosystem services, this task is termed "benefit transfer", but the general principle of using specific observations and applying them to estimate values for a broader population is applicable to all ecosystem measurement. Indeed, it is standard practice in socioeconomic surveys. The particular challenge for ecosystem accounting is finding the correct levels of stratification of environmental features (e.g., vegetation types, climate, elevation) so that observations can be appropriately scaled. There are a range of approaches to benefit transfer for ecosystem measurement. An introduction is provided in chapter V of SEEA EEA; and several papers in the scientific literature (e.g., Plummer (2009)) provide further insights.

2.64. Sixth, one general ambitious aim in the implementation of ecosystem accounting is to facilitate the comparison of information on ecosystems within and between countries. Comparison of information has the ability to serve as an important basis for policy discussions and can support analysis and data exchange. That is especially relevant with respect to transboundary environmental stocks and flows, such as water and migratory species. The purpose of establishing comparability within ecosystem accounting is to determine agreed measurement boundaries and definitions and associated classifications, as reflected in an agreed ecosystem accounting framework. The aim is not, however, to ensure that there is commonality in method, since differences in method are likely appropriate in different contexts.

2.65. At this stage in ecosystem accounting, while there is good progress being made towards the creation of an agreed framework, there is also the recognition that further discussion and testing are of course needed. There has been far less agreement or commonality exhibited with respect to the methods to be applied in ecosystem accounting. That is due in part to the significant differences in the applications of the ecosystem accounting framework, which naturally leads to the use of different fit-for-purpose methods and data sources. It also reflects the breadth and variety of connections between ecosystems and people, which need to be taken into consideration.

2.66. With these points in mind, the ecosystem accounting framework described in SEEA EEA, and as advanced in these *Technical Recommendations*, should be viewed as well-established and as providing the basis for comparison and discussion. At the same time, there is also room for considerable flexibility in the implementation of the framework. Hence, the methods discussed and the proposed structure of the various ecosystem accounts should be taken as a guide to the types of information that can be organized following a given accounting logic. Countries are encouraged to compile accounts using structures and methods that are most appropriate to an understanding of the relationship between their own ecosystems and their economy. Nonetheless, to support ongoing dialogue and international comparison, it is essential that the relevant definitions, structures, classifications, concepts and resulting indicators are coherent with the core framework presented in the *Technical Recommendations*. And if there are variations used, they should be presented and described together with the accounts.

2.67. The future design of ecosystem accounts will benefit from further testing and discussion with respect to both the relevant compilation approaches and the most appropriate levels for analysis and communication of results.

Chapter III
Organizing spatial data and accounting for ecosystem extent

Key points

- Ecosystem accounting requires the delineation of the mutually exclusive units within a country that represent ecosystem assets (EAs).
- Ecosystem assets are the distinct contiguous spatial areas that form the conceptual basis for accounting and the integration of relevant statistics. Each EA is covered by a specific ecosystem type (e.g., a single deciduous forest).
- Ecosystem types (ETs) are aggregations of individual EAs of a specific type of ecosystem (e.g., deciduous forests).
- In the accounts, information may be reported by individual EA or by ET. Typically, when accounts are developed at aggregated scales such as the scales of countries, the number of EAs is too large to allow for meaningful reporting by individual EA, and accounts report information on ecosystem extent, ecosystem condition and ecosystem services by ET.
- Accounts are generally produced for relatively large administrative areas, such as provinces, States or countries, or in relation to large areas such as continents, bioregions or river basins that may cross national boundaries. The area for which an account is produced is called the ecosystem accounting area (EAA). EAAs are geographical aggregations of EAs that can be grouped by ET.
- Basic spatial units (BSUs), in the form of grid squares or small polygons, support the delineation of EAs and ETs and the organization of spatial data sets for ecosystem accounting. For measurement purposes, BSUs are assumed to be internally homogeneous in terms of their biophysical properties.
- Producing the accounts requires data on, for instance, topography, vegetation, land use and hydrology. In a fully spatial approach, all spatial data sets should be brought together in a consistent manner using the same reference coordinate system within a common spatial data infrastructure.
- A key challenge in producing accounts is securing access to different data sets, both spatial and non-spatial, and integrating the data effectively. It is therefore important that collaboration be sought with the various agencies holding the data sets required for the production of the accounts. As that may be time-consuming, such collaboration should be pursued in an early phase of account development.

3.1. Introduction

3.1. To provide a starting point for measurement, SEEA EEA applies the definition of ecosystems found in the Convention on Biological Diversity.[14] In article 2 ("Use of terms") of the Convention, an ecosystem is defined as "a dynamic complex of plant,

[14] *United Nations Treaty Series*, vol. 1760, No. 30619.

animal and micro-organism communities and their non-living environment interacting as a functional unit". Delineating ecosystems spatially for measurement purposes is not a straightforward matter. In ecological terms, ecosystems may be defined at a range of spatial scales; hence, as it is often difficult to identify clear boundaries, they may overlap in spatial terms. For statistical and accounting purposes, however, it is necessary to clearly differentiate ecosystem assets as discrete units, which means that the boundaries described here should be considered a statistical abstraction from an ecological reality.

3.2. Ideally, in ecosystem accounting, all ecosystems within the area for which the accounts are developed should be included. Urban areas, including sealed surfaces, should also be identified, even though they may be home to very few plant and animal species and may provide relatively few ecosystem services. Where the accounts include entries for types of ecosystems, the different ecosystems need to be delineated so that there are no gaps or overlaps, that is, the approach must be mutually exclusive and collectively exhaustive.

3.3. A framework covering three types of spatial areas has been developed to enable the organization of information to reflect separate entities that can then be compared and aggregated. That framework is akin to the units model in economic statistics, in which economic units (i.e., businesses, households and governments) are distinguished by their types of economic activity and legal structure. These units can then be grouped into relevant types, such as industry classes and institutional sectors.

3.4. The present chapter outlines the approach taken in SEEA EEA to organize spatial data and account for ecosystem extent, building on the discussion found in SEEA EEA, section 2.3. The chapter covers, in particular, the framework for delineating spatial areas for ecosystem accounting (sect. 3.2); the ecosystem extent account and its role as the basis for ecosystem accounting (sect. 3.3); how the ecosystem extent account can be compiled (sect. 3.4); the spatial infrastructure, measurement and data layers (sect. 3.5); recommendations for developing a national spatial data infrastructure (sect. 3.6); and key research issues associated with the delineation of spatial areas for ecosystem accounting.

3.5. The basic terminology and concepts related to spatial units are applicable to all approaches to the implementation of ecosystem accounting. The distinction is that in a fully spatial approach, a much larger set of information on ecosystems is mapped, while in a minimum spatial approach, ecosystem services are mapped and modelled only where that is required to obtain the information needed to fill the accounting tables.

3.6. In a fully spatial approach, in which all ecosystem service flows and ecosystem assets are mapped, the spatial infrastructure for ecosystem accounting may require substantial data storage and computer processing power. In large countries, ecosystem accounting that is pursued at high resolution requires powerful stand-alone computers with, potentially, (some) data storage on internal or external "cloud" servers. Key considerations related to data handling and computing are provided in the following sections.

3.2. Framework for delineating spatial areas for ecosystem accounting

3.2.1. Introduction

3.7. The conceptual framework for ecosystem accounting involves the integration of data relating to three types of spatial units or areas: ecosystem assets (EAs), ecosystem types (ETs) and ecosystem accounting areas (EAAs). Those areas are key elements of the ecosystem extent account and provide the basis for spatial analysis in the other ecosystem accounts. Each of the three types of areas is described in the present section (see also figure 3.1).

3.8. At this stage in the development of ecosystem accounting, considerable flexibility is exercised regarding how the different types of areas may be delineated in practice. Both relatively coarse and relatively fine delineations may be applied. For example, linear landscape elements such as hedgerows may be distinguished as specific ecosystem assets. Further, the criteria used to delineate ecosystem assets may be quite varied. They may be based only on ecological factors or may also take into account aspects of ecosystem use and management.

3.9. At the same time, there are three principles that should underpin the definition and delineation of spatial units for ecosystem accounting purposes. First, for a given ecosystem accounting area (e.g., a country), the set of ecosystem assets should cover the entire territory (i.e., all areas should be classified) and the spatial boundaries should not overlap (i.e., the areas should be mutually exclusive). Those requirements ensure that, from a statistical and accounting perspective, the picture presented is both complete and non-duplicative.

3.10. Second, the classification associated with the spatial data that are used to delineate spatial areas should be sufficiently detailed to encompass a range of ecosystems spanning a country or EAA that is appropriate for analysis and decision-making. For example, if a limited set of ecosystem types is covered, then it may be possible to provide only generalized depictions of changes in ecosystems; on the other hand, through the inclusion of a greater number of ETs, development of a more detailed analysis might be possible.

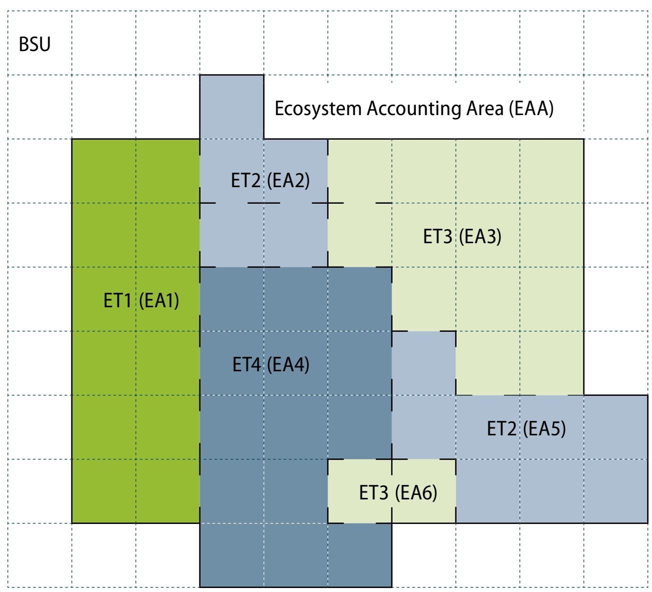
3.11. Third, for a single set of ecosystem accounts, comprising, for example, extent, condition and ecosystem services accounts, for a given ecosystem accounting area, the classification of ecosystem types that is used should be common to the different ecosystem accounts and any associated thematic accounts. For example, the area of wetlands reflected in an ecosystem extent account should also underpin the measurement of the condition of wetland areas and the measurement of ecosystem services related to wetlands. Where there are different sets of accounts for a given country—e.g., a set of national-level ecosystem accounts and a set of ecosystem accounts developed for a specific area within that country, such as an individual water catchment—areas may be classified in different ways as a result of differences in the focus of the accounting. However, in these situations, it will be appropriate to adopt some sort of correspondence.

3.12. The requirement for consistency across a set of accounts does not imply that the delineated areas cannot change over time. Indeed, the expectation is that over time, through the use of the same criteria, different boundaries would be delineated for individual ecosystem assets to reflect their changing areas, and that the accounting would be so designed as to be able to record such changes. Under the third principle, it is expected that those changes would be reflected consistently in all accounts for the same point in time in the same way.

3.13. Constructing a framework for the delineation of spatial areas may appear to be a relatively linear task in which spatial areas are defined, measurements are taken and accounts are then compiled. In practice, a linear sequence is unlikely. Instead, it should be expected, particularly in the initial testing of ecosystem accounting, that, in compiling each estimate, a high degree of iteration will occur between: (a) the delineation of ecosystem assets; (b) the classification of ecosystem types; and (c) the measurement of ecosystem condition and ecosystem services. Ultimately, building on an emerging understanding of the more relevant connections between ecosystems and economic and human activity, a balance will need to be struck as regards the availability of data and their intended use. This initial work will also highlight those areas in which additional investment in data can yield the greatest value.

3.14. A stylized presentation of the spatial structure of the ecosystem extent account is found in figure 3.1, which displays relationships among the EA, the ET and the EAA. The EAA boundary is defined by the thick line. The figure delineates six distinct EAs that are classified to four different ETs. The figure also incorporates the basic spatial unit (BSU), the spatial unit of measurement, which is discussed in section 3.5. BSUs may correspond, as in figure 3.1, to cells on the grid of a spatial information system or to individual polygons in cases where a vector-based approach to ecosystem extent accounting is adopted.

Figure 3.1
Relationship between spatial areas in ecosystem extent accounting



Source: Adapted from SEEA EEA, figure 2.4.

Note: Ecosystem assets represent individual, contiguous ecosystems. Ecosystem types are aggregations of ecosystem assets of the same type.

3.2.2. Ecosystem assets

3.15. Conceptually, for accounting purposes, each area covered by a specific ecosystem type is considered to represent an ecosystem asset. Ecosystem assets (EAs) are considered to be contiguous and to be bounded spatially, with each asset comprising all the relevant biotic and abiotic components within its boundaries that are required for the EA to function and to supply ecosystem services.

3.16. In principle, an EA can be differentiated from neighbouring EAs by both ecological and ecosystem use factors. From an ecological perspective, EAs can be differentiated by the extent to which the relationships between biotic and abiotic components within the EA are stronger than the relationships with components outside the EA. Those differences in relationships are reflected in differences in function, structure and composition. Hence, EAs are delineated, ideally, based on various characteristics such as vegetation structure and type, species composition, ecological processes, climate, hydrology, soil characteristics and topography. Those characteristics may be utilized alone or in combination. The choice depends on the country, the ecosystems involved, the detail required for policy and analysis, and the data available.

3.17. Information on ecosystem management and ecosystem use is also relevant to the delineation of EAs and may be particularly helpful in understanding the most likely flows of ecosystem services from a particular EA. For example, it may be useful to distinguish between protected forests that are not logged and other, ecologically similar forests in which logging is permitted. It should also be noted that maps that delineate land within a country according to different land management regimes (e.g., for protected areas and water catchments) may be readily available and can be used to support the establishment of spatial areas for ecosystem accounting. It should be recognized that the greater the number of ecological and ecosystem use characteristics utilized for delineation, the greater the number of EAs that will be identified.

3.18. If various data on ecological and use characteristics (see paras. 3.16–3.17) are not available, a land-cover-based delineation of EAs may be used as a starting point. That raises the practical question of which land cover classes should be considered and at what level of detail. For EAs delineated based on land cover, it is recommended that, where possible, a country should use the most refined set of land-cover types available for its country so as to provide as close a match as possible with known ecosystem typologies. Where country-specific detail is not available, the coarsest-level classification to be applied is the interim land-cover classification in SEEA Central Framework (United Nations, European Commission, FAO, IMF, OECD and World Bank, 2014), which has 15 classes, as shown in table 3.1.[15] Each of these 15 land-cover classes may be used to represent an ecosystem type, but should be further subdivided into more detailed types, where possible. A class for sea and marine areas should be incorporated to ensure appropriate coverage for all areas within the ecosystem accounting area.

3.19. Where an individual ecosystem crosses a country's national boundary, the associated EAs need to be delineated with reference to the national boundary to ensure that the aggregate of all EAs for that country is equal to the total country area.

3.2.3. Ecosystem types

3.20. EAs are contiguous areas representing individual ecosystems. In practice, given that accounts are normally developed at aggregated scales, such as that of countries or large water catchments, it may be difficult to analyse, record and report data for each individual EA. It is therefore relevant to analyse accounting variables, such as ecosystem condition and ecosystem service supply, at a more aggregated level, reflecting information for EAs of the same type.

3.21. For example, ecosystem account users may be interested in information on the ecosystem services supplied by all EAs of the type "deciduous forest", rather than in services from individual patches of deciduous forests. Alternatively, data may be sufficient to provide only an estimate of the total supply of an ecosystem service for a specific type of ecosystem, and hence cannot provide a meaningful indication of service supply in each associated individual EA.

[15] SEEA EEA proposed a set of 16 classes for land cover/ecosystem functional units. These classes were developed as an application of the interim land cover classes presented in the SEEA Central Framework by combining land cover information with information on land use. Since there may be various ways in which land-use information and land cover information may be combined, it is now considered that for the task of attributing land cover characteristics to EAs, the starting point should be the land cover classification of the SEEA Central Framework. For a more detailed description of land cover classes, see the Central Framework, annex I, sect. C.

3.22. Accordingly, an ecosystem type is defined as a specific class of ecosystem assets of comparable ecology and ecosystem use. Generally, across a country, there are a number of different EAs covered by the same ET. For example, there may be different areas of mangrove forest in different parts of a country. While each individual mangrove forest is considered a separate EA, it is classified to the same ecosystem type (ET).

3.23. ETs can be viewed as aggregations of ecosystem assets of a similar type, and EAs can be viewed as contiguous areas of a specific ecosystem type. In practice, an ecosystem accountant needs to start with a classification of ecosystem types in order to delineate ecosystem assets.

3.24. In defining ETs, it is helpful to consider the supply of ecosystem services, and to aim for a high degree of commonality in ecosystem services supply within an ET. For instance, grasslands in floodplains provide an important hydrological service (water storage resulting in reduced flood risk), whereas grasslands outside of floodplains do not provide this service. Thus, even though those areas have similar vegetation cover, it is helpful to attribute them to different ETs, thereby facilitating a coherent linkage between the ET and the ecosystem service supply. Similarly, ecological detail for the type of perennial crop, or the hydrological properties of a forest, facilitates identification and analysis of the ecosystem services supplied by those ETs.

3.25. However, as the classification of ETs becomes more detailed, the accuracy of the information used to identify them may decrease, depending on the data source. While, in practice, a balance must be achieved between the number of different ETs that are identified and the availability of information to identify them, it should be noted that the use of a limited number of types will also limit the scope and depth of the questions that can be answered using the accounting information.

3.26. In general, land-use classifications are more specific, and include a greater number of classes, than land-cover classifications. In the same way, classifications of ETs are normally more detailed than land-use classifications since, in addition to land use, ET classifications consider ecosystem services. Even if their uses are similar, those services may differ because of their hydrological properties (e.g., as mentioned in para. 3.24).

3.27. Specification of ETs requires consideration of land cover, land and ecosystem use and the ecosystem services provided. Those services are affected by such factors as natural vegetation, institutional arrangements, location in the landscape, hydrology and/or soil type. At the same time, the classification of ETs should not be prohibitively complex. In the classification of ETs based on land use, it is recommended that only selected ecosystem services be considered—typically less than five—as well as how they are supplied by different ecosystems. For example, in low-lying areas, services related to flood control may be of significant interest; in dry areas, services related to sustaining water flows may be of high importance; and in mountain areas, erosion control services (e.g., headwater and riparian vegetation) may be essential, which merits the inclusion of those services when delineating specific ETs.

3.28. Table 3.1 presents examples of ETs and illustrates the difference between them and land-cover classes. By demonstrating that ETs are typically nested within land-cover classes, the table facilitates the recognition that differences in ecological characteristics should be a prime consideration in differentiating among ETs. It should also be noted that there is an important similarity between ETs and the classes that often make up land-use classifications. Generally, only when land-use classes provide significantly different baskets of ecosystem services is it useful to separate them into different ETs.

Table 3.1
Provisional list of land-cover classes and ecosystem types

Land-cover classes (SEEA Central Framework)	Possible ecosystem types
Artificial areas (including urban and associated areas)	Residential zones and housing Urban parks Industrial uses (e.g., factories) Road infrastructure Waste deposit sites
Herbaceous crops	Irrigated rice Other irrigated crops Rain-fed annual crops
Woody crops	Fruit tree plantations Coffee and tea plantations Oil palm plantations Rubber plantations
Multiple or layered crops	Two layers of different crops (e.g., wheat fields and olive trees in the Mediterranean area) One layer of natural vegetation (mainly trees) that covers one layer of cultivated crops (e.g., coffee grown under shade trees)
Grasslands	Natural grasslands Improved pastures Steppes Savannahs
Tree-covered areas (forests)	Deciduous forests Coniferous forests Plantation (planted) forests
Mangroves	Inland mangroves Mangroves near shore
Shrub-covered areas	Natural dry-land shrub land Degraded dry-land shrub land
Shrubs and/or herbaceous vegetation, aquatic or regularly flooded	Wetland shrub land
Sparsely natural vegetated areas	Periglacial vegetation
Terrestrial barren land	Sandy dunes
Permanent snow and glaciers	
Inland water bodies	Lakes Rivers
Coastal water bodies and intertidal areas	Coral reefs Seagrass meadows
Sea and marine areas	

Note: The left column is derived from the SEEA Central Framework, table 5.12.

3.29. Experience to date with the development of ecosystem accounts for coastal and marine areas is more limited. However, given that different marine areas provide different ecosystem services, it is appropriate to distinguish among specific ecosystem types within the land-cover class comprising coastal ecosystems (e.g., seagrass meadows, coral reefs, oyster and mussel banks, mangroves, rocky substrates, sandy substrates, etc.). The land-cover class comprising marine ecosystems could potentially be further differentiated among, for example, reefs, sandbanks, the continental shelf and the deep sea.

3.30. While there have been relatively few projects focused on accounts for urban ecosystems, it would seem feasible for the various ecosystem types in urban ecosystems to be differentiated as well, based on the land-cover and land-use classes in which they are nested and the services that they supply. Those ecosystem types may include urban parks within city boundaries, various types of parks that are near cities but outside residential zones, and even specific areas such as rivers flowing within urban areas, riverbeds, canals and cemeteries.

3.2.4. Ecosystem accounting areas

3.31. Conceptually, it is possible to develop a set of ecosystem accounts for an individual EA, such as a forest, wetland or farming area. That would be akin to developing financial accounts for individual businesses. It is also possible to develop a set of ecosystem accounts for a specific ET (e.g., all grasslands in a country). However, in overall terms, the ambitious goal underpinning SEEA EEA is to provide more general guidance on the changes in ecosystem-related stocks and flows in larger and diverse spatial areas.

3.32. To provide a larger picture of ecosystems, it is necessary to consider aggregations of EAs that provide information at a scale: (a) that is relevant for policy monitoring and analysis; and (b) where the accuracy of the information is considered fit for purpose.

3.33. At the most aggregated levels, that involves accounting at the national or, in particular cases, at the continental level,[16] that is, accounting covering all EAs within a country or group of countries. Commonly, however, it is appropriate to create aggregations of:

(a) EAs and ETs within specific subnational administrative areas;

(b) EAs and ETs within hydrologically defined areas within a country (such as water catchments);

(c) Other areas of policy-related interest such as protected areas or areas owned by specific industries or sectors, for example, government-owned land.

3.34. Commonly, those aggregations reflect contiguous areas, such as administrative areas or river basins, but it is not a requirement for accounting purposes. The geographical aggregation for which the account is developed is referred to as the ecosystem accounting area.

3.35. Within each ecosystem accounting area (EAA), there are multiple EAs grouped into different ETs, for example, individual EAs of forests, wetlands and cropland. The resulting accounting structures, as introduced in chapter II, are such that measures of ecosystem extent, ecosystem condition and ecosystem services will present information for aggregations of EAs into ETs. For example, for a given subnational administrative area, an ecosystem extent account would show the changing total area of each ET (e.g., forest, wetland or cropland) but not the changing area of each individual EA.

3.36. A single EA may be classified to multiple EAAs, for example, to an EAA formed using a water catchment, as well as to an EAA formed using an administrative region. The relevance of incorporating a single EA into different EAAs depends on the question being addressed.

[16] As in the European Union Knowledge Innovation Project for an Integrated System for Natural Capital and Ecosystem Services Accounting in the EU (KIP INCA) described in annex II.

3.3. Ecosystem extent account

3.37. The most common starting point for ecosystem accounting entails organizing information on the extent of various ecosystem types within a country in terms of area. The structure of a basic ecosystem extent account is shown in table 3.2. The structure of the rows reflects the basic logic of asset accounts as described in SEEA Central Framework, with an opening extent (in hectares or square kilometres), closing extent, and additions and reductions to extent. The column headings correspond to the chosen land-cover classes for ecosystem types. In the structure proposed here, the high-level ecosystem types used are based on the categories of the interim land-cover classification in SEEA Central Framework. Additional subclasses may be added depending on the most relevant ecosystem types within a country. An example involving more detailed subclasses is provided in table 3.1.

3.38. In cases in which the type of land cover is the only characteristic used to delineate different ecosystem assets, the land-cover account and the ecosystem extent account are identical. Use of additional characteristics to delineate ecosystem assets are expected to yield different results.

Table 3.2
Interim ecosystem extent account based on SEEA Central Framework land-cover classes (hectares)

	Proxy ecosystem type (based on land cover)														
	Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and intertidal areas	TOTAL
	1	2	3	4	5	6	7	8	10	11	12	13	14	15	
Opening extent															
Additions to extent															
Managed expansion															
Natural expansion															
Upward re-apppraisals															
Reductions in extent															
Managed regression															
Natural regression															
Downward re-appraisals															
Net change in extent															
Closing extent															

3.39. From an accounting perspective, it is important to recognize that the total area of a country, incorporating marine areas as appropriate, is unlikely to change over an accounting period.[17] Hence, the total area recorded in the right column should be the same for the opening and closing stock and should remain unchanged irrespective of the number of different ETs that are introduced into the table. Where the total land area does change—owing, for example, to land reclamation—the compiler should record the change against the relevant addition or reduction following the advice provided in section 5.6.3 of SEEA Central Framework. Changes in area due to political factors should be recorded as upward or downward reappraisals.

[17] Although there may be seasonal or other regular variations in area in some coastal ecosystems.

3.40. For the ecosystem extent account presented in table 3.2, there is no requirement that, as regards each type of ecosystem, their areas be contiguous. That is, the total area of, for example, grassland, is spread out across a country in various EAs, contiguous or not, and the data in table 3.2 will reflect an aggregation of all of those EAs.

3.41. It would be useful to present information from an ecosystem extent account in map format using different colours for different ETs. Issues of fragmentation of ecosystem types and possible connections between them that are not readily apparent when the information is presented in a traditional table format can be more easily highlighted by mapping that information.

3.4. Compiling the ecosystem extent account

3.42. The ecosystem extent account is the basis for ecosystem accounting. It is usually the first ecosystem account to be developed. When the ecosystem extent account is being compiled, the main challenges are related to making informed choices with respect to the ETs to be distinguished and the resolution of the maps and the minimum mapping unit. The starting point is usually an examination of the land-cover, land-use and ecosystem maps already available in a country (or other area for which the accounts are to be produced) and the task in this regard is to determine how information in such maps can be combined to produce an ecosystem extent account and map that reflects the composition of ETs. It will need to be decided, based on these information sets, whether a raster- or a vector-based approach is to be used to produce the ecosystem extent account (see also sect. 3.5).

3.43. In addition, the decision may be taken to extensively incorporate more detailed information for individual EAs, particularly when accounts are produced for smaller areas. This will increase the resolution at which data on ecosystem services flows and assets would need to be compiled.

3.44. The framework for delineating spatial areas focuses on ecological characteristics, ecosystem use and ecosystem services. Further, since all data layers are connected to a common reference coordinate system, it is possible to overlay different types of spatial information (data layers) in different ways for accounting purposes.

3.45. In many countries, cadastres—registers of areas defined administratively and delineated on the basis of landownership—are well established. Information from cadastre-based data sets can be linked to information on EAs, ETs, economic activity and land use, as well as to other socioeconomic information. For instance, it is possible to combine information on landownership (tenure) with information on ETs and water catchments as a means of clarifying the details of ownership of ETs within each water catchment.

3.46. The use of cadastre-based information is likely to be meaningful in terms of understanding the link of landownership to policy initiatives, particularly in those countries where land is under private ownership. However, it is not recommended that landownership data be applied directly to delineation of EAs, since this kind of information may be sensitive in many countries. Furthermore, depending upon the size of the cadastres, it may be common for a single cadastre to comprise multiple EAs.

3.5. Spatial infrastructure, measurement and data layers

3.5.1. Basic spatial units

3.47. While EAs, ETs and EAAs constitute the spatial areas for accounting and statistical purposes, for many ecosystem measurement-related purposes and as a basis for constructing the accounts, a spatial measurement unit is needed. In ecosystem accounting, this small spatial area, a geometrical construct, is referred to as a basic spatial unit. The purpose of BSUs is to provide a fine-level framework within which a range of information can be incorporated. The precise definition of a BSU depends on the context and the nature of the approach taken to managing spatial data for accounting.

3.48. In developing a spatial data infrastructure for accounting, it is necessary, first, to select and set up a hardware and software environment which is integrated into a geographic information system (GIS). This usually entails the use of a GIS software package such as ArcGIS or Quantum GIS. Adequate data storage and computing power are also required.

3.49. Next, a specific reference coordinate system needs to be selected. Ecosystem accounting relies on the integration of different spatial data sets or "layers". It is therefore necessary that all spatial data layers, whether containing raster (grid) or vector data, be converted to the same reference coordinate system for analysis. Countries generally have a specific reference coordinate system, and either this system or a global reference coordinate system (such as the World Geodetic System 1984 (WGS 84)) can be used for the ecosystem accounts.

3.50. When global data sets are used to complement national data, it needs to be verified that the same reference coordinate system be used for all data sets and if not, spatial data should be corrected for this, through application of standard procedures in GIS for connecting spatial data to the selected reference coordinate system.

3.51. Of significance also is the projection system that is used to map the three-dimensional surface of the Earth onto a two-dimensional spatial data layer. When grid-shaped BSUs are part of the spatial data infrastructure, an equal-area projection is normally recommended so as to ensure that all grid cells are of the same size.

3.52. Once this infrastructure is in place, the data sets to be used for the accounts can be integrated into the selected spatial data environment. Typically, ecosystem accounting involves the integration of: (a) data from national accounts; (b) surveys; and (c) spatial data from various sources, including thematic maps and remote sensing. Spatial data are usually available at different resolutions (thematic maps often use polygons; remote sensing data may be available at 30 metre grid size (Landsat) or, increasingly, at 10 metre grid (Sentinel-2)) so that data gaps can be filled, data can be interpolated and extrapolated, where appropriate, to establish wall-to-wall maps (i.e., maps with no missing or undefined cells) of relevant variables for the different accounts.

3.53. A flexible approach to defining BSUs and analysing spatial data is proposed, in recognition of the large differences across countries in terms of spatial area, ecological characteristics and data availability. A fundamental decision to be made in setting up the spatial data infrastructure is whether to use a reference grid and, if so, whether to use it to integrate all data layers; or, instead, to allow different data sets to have different formats (grid or vector) and/or different grid sizes.

3.54. A reference grid approach should be understood as entailing the establishment of a grid with a single reference coordinate system and with an agreed grid size, for example, 100 metres by 100 metres. For all data layers, data are attributed to the reference grid cells so as to ensure that for every data layer there is a specific value for each reference grid cell. Such an approach has the advantage of reducing the quantity of data involved and the complexity of the spatial modelling.

3.55. Where a reference grid is established, a key question is what the size of the grid squares should be for ecosystem accounting purposes. There are three main factors to be considered in the selection of grid square size: (a) the resolution at which data are available; (b) the spatial variability of the ecosystems within the EAA; and (c) the potential limitations to computational capabilities and data storage. For example, an EAA with many small landscape elements such as forest patches and hedgerows requires a finer (smaller) grid compared with EAAs with large-scale landscape elements (e.g., savannahs).

3.56. In general, grids ranging in size from, typically, 25 metres by 25 metres to 100 metres by 100 metres can be recommended as a good starting point for accounting purposes. It should be noted, however, that larger grid sizes may be appropriate when accounting is undertaken at the continental scale. Establishing grid sizes of 10 metres or smaller is now possible in some countries, but whether delineation at that level of detail is required or appropriate for ecosystem accounting should be determined based on how the accounts are used in decision-making. The use of a single reference grid generally reduces the accuracy of some of the data. Furthermore, the larger the grid squares, the higher the level of inaccuracy that is introduced by conversion of individual data layers to the reference grid.

3.57. Each cell in the established reference grid represents a BSU. Under that approach, a range of information is attributed to each BSU, including, for example, details on EAs, ETs, land cover, soil type, elevation and other biophysical and/or socio-economic information.

3.58. The alternative to using a reference grid—an alternative that is perhaps more appropriate for smaller EAAs—is to include spatial data sets with different resolutions, for instance, a combination of relatively coarse vector-based thematic data, a more detailed vector-based topographic data set, ecosystem condition indicators sampled with remote sensing imagery of 30-metre resolution and other ecosystem condition indicators sampled at 10-metre resolution. Provided that a consistent reference coordinate system is employed for all data layers, the various data sets can be used and integrated in the accounting structure. An advantage of this approach is that there is no loss of information due to the aggregation of data sets to a specific grid. However, depending on the number of data layers that are combined, the resulting intersecting areas may be small, and additional computational resources may be needed.

3.59. Where a reference grid is not used, the EAs and the ETs may be defined in the ecosystem extent account using either a raster- or a vector-based approach. As noted, that account is the basis for ecosystem accounting. A raster-based ecosystem extent map is usually the result of an analysis of remote sensing images, whereas an ecosystem extent map based on a combination of topographic and thematic data sets typically appears in vector format. It should be noted that the use of a vector format is especially relevant for the analysis of linear and point elements in the landscape, in particular elements that may not be covered accurately using a raster map, such as roadsides, hedgerows, streams or, in an urban context, individual trees.

3.60. In addition, where no reference grid is used, each data layer may have its own specific resolution. In that case, the BSU represents the smallest spatial unit underlying the ecosystem extent account, which, as indicated, may be in either a raster or a vector format. It is to be noted that in a raster-based approach to ecosystem extent accounting, an EA may be composed of one or a set of BSUs of the same ET. In a vector-based ecosystem extent account, the BSU corresponds to individual polygons, which are likely to represent areas of different sizes. In a vector-based approach, typically, one EA is represented by one BSU.

3.5.2. Data layers and delineation

3.61. The delineation of spatial areas and the analysis of ecosystem service flows involves the use of a range of spatial information including:

- Land cover and land use derived from either existing maps and referenced point data or based on additional remote sensing imagery;
- Topography of the country (coastlines, slopes, river basins and drainage areas), as measured by the digital elevation model;
- Vegetation type and habitat type;
- Species composition;
- Hydrology (river and stream networks, lakes, groundwater flows and aquifers);
- Soil resources and geologic data;
- Meteorological data;
- Bathymetry (for coastal areas);
- Administrative boundaries;
- Population, built-up areas and settlements;
- Transport and communication (roads, railways, power lines, pipelines).

3.62. In some instances, data layers may be only partially populated, that is, the spatial cover of the data may not extend to the full EAA, or it may entail georeferenced point data rather than maps. In those cases, the unpopulated areas of each spatial layer need to be classified as either "no data" or "unclassified", or the missing data need to be modelled or interpolated and extrapolated, so as to ensure consistent coverage and reporting. Various spatial interpolation tools, such as inverse distance weighting, kriging or maximum entropy modelling may also be used in this case (e.g., Schröter and others (2015) and Willemen and others (2015)). In choosing the appropriate approach to populating data layers, the type of data and the experience of experts in the specific measurement area should be taken into consideration.

3.63. With these data sources and tools in place, there are a range of choices available for delineating the spatial units needed for ecosystem accounting. Choices will depend on scale (i.e., the level of spatial detail) and thematic detail (the number of classes in the classification). The following considerations are relevant beyond those described in section 3.2 and building on the discussion on BSUs in paragraph 3.60.

3.64. First, there is no standardized method for delineating EAs. However, there needs to be an awareness that when the ecosystem accounts are developed for a country or part of a country, it is important to build upon existing environmental and other data sets. That allows for efficient use of available data, facilitates the integration of data sets and prevents the production of partially overlapping data sets. Countries generally have land cover- or ecosystem-type maps that can be used as a basis for preparing an ecosystem extent account inclusive of a mutually exclusive and exhaustive definition and delineation of EAs. Depending upon the EAAs and the diversity of ETs, the compilers of the ecosystem accounts may decide to delineate individual EAs or to work instead on the basis of ETs.

3.65. In delineating EAs, it is recommended that, wherever possible, the initial focus be on ecological principles, since EAs are considered to be the units that function to supply ecosystem services. Habitat/biotope and vegetation classification methods are expected to offer the most suitable inputs for delineation. However, it is also relevant to consider the services supplied by ecosystems in the delineation of EAs. For example, in the Netherlands ecosystem extent account, it was decided to distinguish floodplains as an ET, given their importance in flood control and water management. Floodplains may have land cover (mostly grasslands) similar to that of other ETs (e.g., pastures), but floodplains were identified as a type based on distinctive hydrology and services supplied (in this example, water regulation).

3.66. For the integration of ecosystem information with socioeconomic data, a potential choice for EAAs are nationally defined statistical areas. Further, statistical areas commonly correspond best to the level of coverage of government decision-making. Depending on the decision-making context, other boundaries are also relevant, including state, province and municipality (specific data may be available from national accounts for those administrative units); landscapes; water provisioning areas; flood/storm protection areas; and protected areas (e.g., national parks). Where statistical data are not available at the desired spatial scale, methods for downscaling data are required.

3.6. Recommendations for developing a national spatial data infrastructure and ecosystem extent accounts

3.6.1. Developing a national spatial data infrastructure

3.67. Within the context of the framework described in this chapter, including the points emerging from the discussion, countries can focus on a number of steps in testing and experimentation in ecosystem accounting. A common principle running through these recommendations is that work for which the goal is to establish the spatial areas required for ecosystem accounting is best undertaken within the broader context of work, whether already completed or planned, to establish a national spatial data infrastructure that would support integration of environmental and socio-economic data. The INSPIRE Thematic Clusters Platform is an example of a project oriented in that direction.[18] It should be recognized that: (a) a national spatial data infrastructure is not essential to the commencement of work on the compilation of ecosystem accounts; and (b) there are many challenges raised by efforts to establish a national spatial data infrastructure that are not presented here. In this broader context, the advances made through the project of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) are of particular importance, as are numerous efforts under way at the national level.[19]

3.68. The first step towards utilization of a national spatial data infrastructure for ecosystem accounting is to take an inventory of the spatial data infrastructure that already exists within a country, in particular within government entities, such as spatial planning and environmental agencies. That assessment should include docu-

[18] See https://themes.jrc.ec.europa.eu.

[19] See http://ggim.un.org/UN-GGIM-Thematic-Groups/.

menting the most commonly used GIS software packages and the available data sets. Wherever feasible, the development of a spatial data infrastructure for accounting should build upon existing infrastructure.

3.69. Subjects to be considered in building upon an existing spatial data infrastructure, or establishing a new one, include, among others, the coordinate and spatial projection system, and whether a reference grid will be used. A reference grid may be most relevant in the context of large areas, large data sets and restrictions in computing capacity. If a reference grid is used, the size of the grid cells needs to be established. It should be noted that resolution is not identical to grid size: resolution refers to the smallest objects visible in an image or map, while grid size signifies the on-the-ground area covered by a pixel. To be visible within an image, objects need to be larger than grid size.

3.70. Another factor to be considered in setting up the spatial data infrastructure is the minimum mapping unit, which is the minimum size of a contiguous area that is required in order for it to be distinguishable in the map. Usually, a minimum mapping unit substantially exceeding the grid size is chosen in order to facilitate interpretation of the map.

3.71. The development of spatial data infrastructure also requires selection of hardware with sufficient processing, storage and backup capacity, as well as GIS software.[20]

3.72. Within a spatial data infrastructure, integration of the following data layers is recommended:

- Official boundaries, including country, administrative and statistical, and river basins, biogeographic areas and shorelines (as polygon vector data);
- Elevation and topography data, based on a digital elevation model. If no detailed country-level data are available, then the global Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data set[21] can be used. The digital elevation model data are important for distinguishing the elevation and slope of the BSU;
- Land-cover data;
- Additional data layers, as available, including:
  - Data on land management and use;
  - Data on vegetation type;
  - Soil and geologic data;
  - Hydrologic data related to rivers, lakes, streams, and coastal and marine areas;
  - Data on urban infrastructure, including cities, villages, industrial zones, and transport (i.e., rail, road), which are needed for assessing ecosystem condition and achieving an understanding of ecosystem use (relevant, e.g., for mapping fragmentation and other impacts);
- Socioeconomic data, including on population, employment and economic activity.

3.73. An important facet of the development of a national spatial data infrastructure and, ultimately, of a national register or listing of ecosystem assets, is an understanding of spatial areas that have already been delineated by government agencies for administrative purposes, for example, land management areas; river basins and catchment management areas; and areas under nature conservancy and protected areas. In

[20] For example, free and open source software, such as Quantum GIS (QGIS), and commercial software, such as ArcGIS.

[21] See https://asterweb.jpl.nasa.gov/gdem.asp.

some cases, these existing spatial boundaries may provide a suitable starting point for ecosystem accounting.

3.74. Further, it is pertinent to acquire an appropriate understanding of the hierarchy of ecosystem/landscape/ecoregion/biome units that are relevant for the country. This can be achieved within the context of existing products (e.g., the list of ecoregions identified by the World Wildlife Fund and the Environmental Systems Research Institute/United States Geological Survey (Esri/USGS) global ecosystems map.[22] Testing and experimentation should identify the most relevant data sources for the delineation of areas for ecosystem accounting purposes, while ensuring that the outcome provides a spatially exhaustive coverage of a country.

[22] See https://www.usgs.gov/centers/gecsc/science/global-ecosystems?qt-science_center_objects=0#qt-science_center_objects.

3.75. It is important to recognize that the ecosystem accounting approach is most useful through development over a period of time. Indeed, given the potential complexity of the accounts, both a step-by-step approach and learning by doing are required. In addition, data will be more useful when both spatial and intertemporal (trend) analyses are possible.

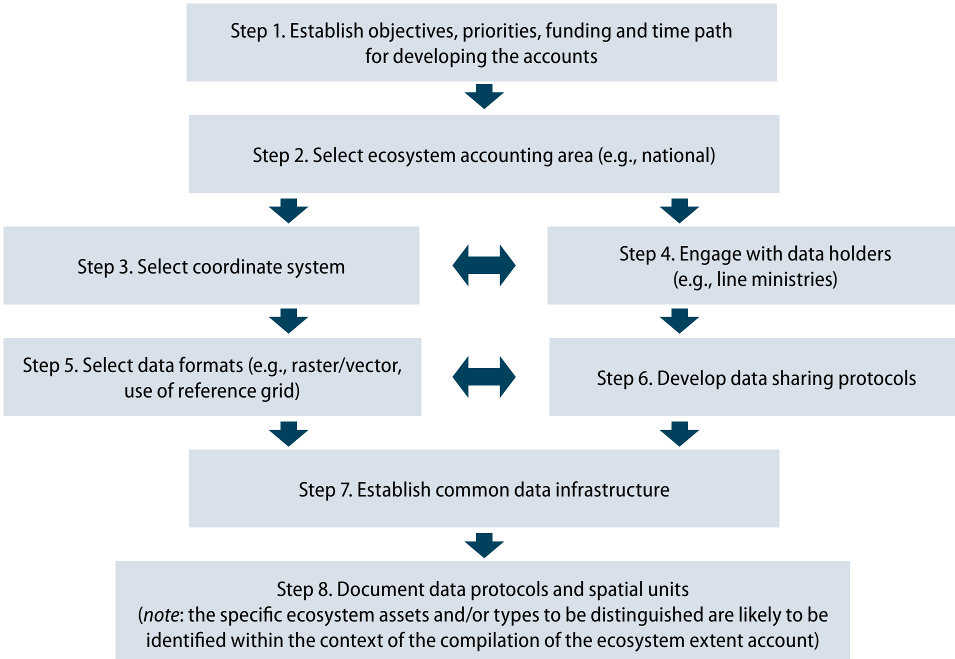
3.76. A critical need in the development of the accounts is for the establishment of data-sharing arrangements and agreement with all the data holders on data access. Data sharing and capacity, even more than data availability, constitute the key bottlenecks. It is recommended that, given the amount of time it may take to establish data-sharing arrangements, that be one of the first priorities in the development of a national spatial data infrastructure. It is also recommended that, in the development of the national spatial data infrastructure: (a) consideration be given to the data formats, including the reference coordinate systems used by the various agencies; and (b) an assessment be made regarding whether similar formats and coordinate systems can be aligned within a national spatial data infrastructure.

3.6.2. Recommendations for developing an ecosystem extent account

3.77. It is likely that in most cases, application of SEEA EEA will start with the development of the extent account, the compilation of which will be best conducted using a national spatial data infrastructure. The key steps in developing a spatial data infrastructure for ecosystem accounting are set out in figure 3.2. The figure shows that the first priority is establishment of objectives, priorities and a time path for the compilation of the accounts, including the development of the national spatial data infrastructure, to be followed by selection of the ecosystem accounting area for which the accounts will be developed. The ambition level of the account determines the relevant territory and the resolution at which data need to be generated, which, in turn, determine hardware and software requirements. Typically, an initial pilot ecosystem accounting project may be run on an up-to-date, powerful stand-alone computer. However, if ecosystem accounting is applied at the level of large countries or at a continental scale, additional computing power, entailing either deployment of a server or cloud computing and data storage, may be required.

3.78. A key step in the compilation of accounts is the development of protocols for data sharing with data holders, which may be time-consuming and may require planning well in advance, where possible. On that basis, a national spatial data infrastructure can be developed, which includes selecting the coordinate system and minimum mapping unit, purchasing or allocating GIS hardware and software, prioritizing the accounts to be developed, capacity-building, developing data sharing protocols, and developing methods and protocols for spatial analyses. Subsequently, the national spatial data infrastructure can be populated with data, with compilation of the ecosystem extent account being a first-priority output.

Figure 3.2
Establishing a spatial data infrastructure and spatial units for ecosystem accounting



3.79. Compiling an ecosystem extent account requires determining whether an existing land-cover and/or land-use data set be used or whether a new data set with new ETs be developed. The answer to that question depends upon the quality and level of detail of available data and maps, the availability of additional data and the available budget.

3.80. In order to facilitate ecosystem accounting, ecosystem extent maps should, ideally, be sufficiently detailed to indicate the uses of ecosystems, by exhibiting, for example, the types of perennial crops grown, the forests being used for logging versus those strictly protected, and natural shrub land compared with shrub land that is the product of forest degradation. Generally, that requires the integration of various data sets, for example, data on land cover; cadastral information indicating land use; soil maps; hydrological maps; information on the location of protected areas; and vegetation maps. A national spatial data infrastructure will prove invaluable for the integration of those data. An example of a relatively comprehensive ecosystem extent map is provided in box 3.1.

3.81. Where additional information or resources are not available, the land-cover map may serve as a starting point for the testing of the ecosystem accounting approach. In that case, the level of spatial detail at which the supply of services can be modelled or made spatially explicit is lower, and the level of accuracy of the accounts may therefore be lower.

Box 3.1
Development of an ecosystem extent account for the Netherlands

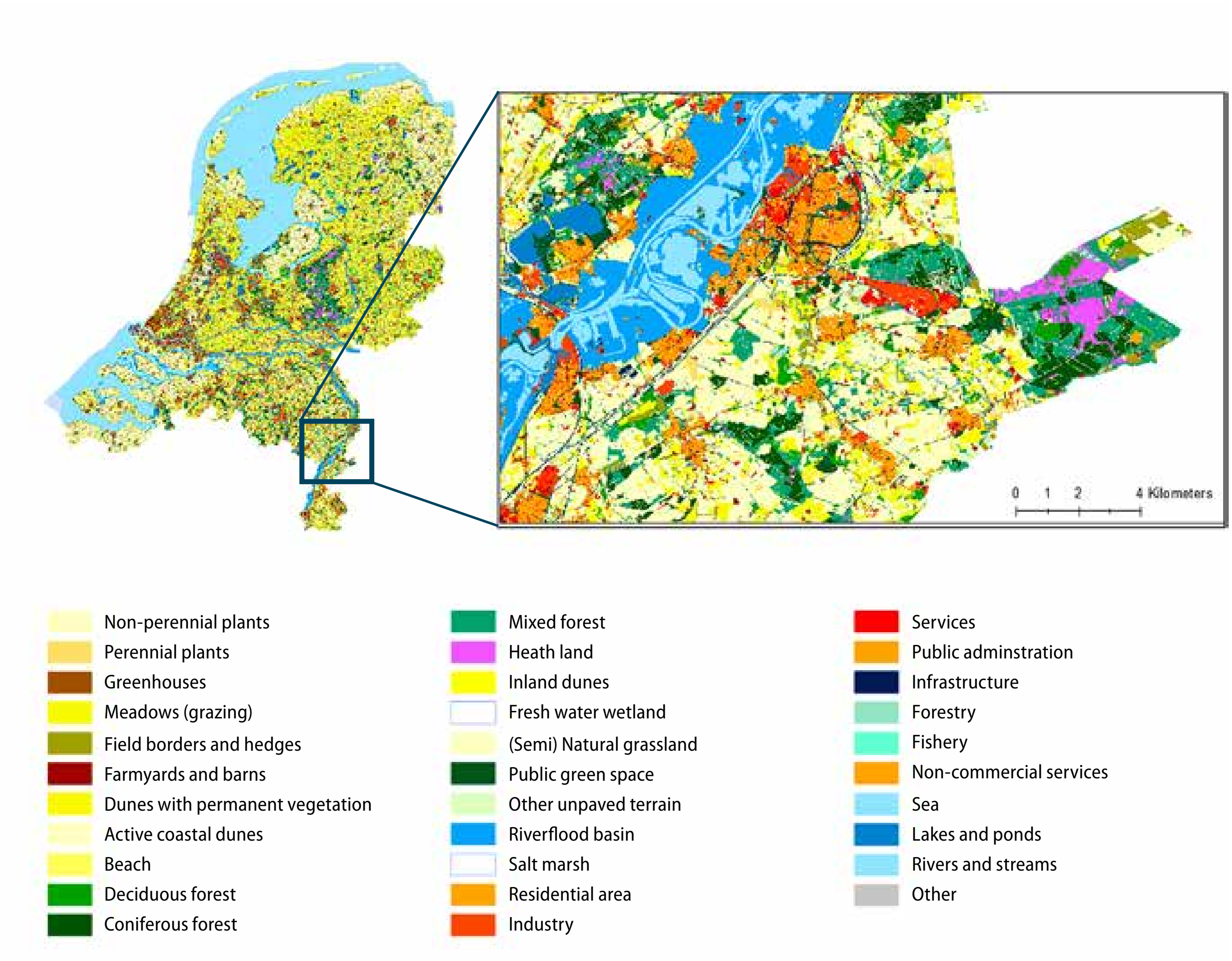
In 2015, Statistics Netherlands, in a project carried out in collaboration with Wageningen University, developed an ecosystem extent account for the Netherlands. The account comprised a detailed map of ecosystem assets in that country, together with a table specifying the number of hectares in each ecosystem type. The map was produced for only one year (2013) and no changes in ecosystem assets were analysed.

The map classified ecosystem assets on the basis of land cover and ecosystem use. Mapping was done, as far as possible, consistent with Mapping and Assessment of Ecosystems and their Services (MAES) and SEEA EEA ecosystem types. In line with SEEA EEA, ecosystem use was defined on the basis of both the management of the ecosystems and the services they provided. In low-lying, flood-prone areas of the Netherlands, water retention and storm protection represent key ecosystem services. Therefore, dunes and floodplains were distinguished as ecosystem types in addition to the main types of SEEA EEA. Floodplains along rivers are used as water retention areas, which are critical for controlling flood risks. The land cover in those floodplains is mostly grassland. That classification is also useful in the compilation of the ecosystem services supply and use account, where water retention is linked to floodplains but not to other types of grassland, such as pastures. A key was provided that enabled reclassification of the ecosystem types to classes of both SEEA EEA and MAES.

The ecosystem extent map was produced through combining several maps and data sets covering the Netherlands: the cadastral map, a map of agricultural crops grown, the address-based business register, addresses of buildings, the basic topographical registry and land-use statistics for the country. The maps were combined following a strict hierarchical approach. For built-up areas, the cadastral unit was taken as the base unit. However, where cadastral parcels were dissected by roads, water or railways, the smaller parcels were taken as the ecosystem asset.

The map illustrates the range of ecosystem and land-use types that characterize the Netherlands. While natural and semi-natural areas were classified in detail (e.g., as wetlands, deciduous forests, heathlands), the same level of detail was applied to intensely managed areas and paved areas (e.g., those containing different types of perennial crops, non-perennial crops, greenhouses, roads). Such a high level of detail allows for precise assessments of, for example land-use intensity and temporal changes in land use. The figure below presents the map at the national scale, with the 31 ecosystem types at the highest hierarchical level. At the next level (not shown), 80 types of ecosystem are distinguished, including various types of forest and perennial crops. At that second level, the map becomes highly suitable for analysing the supply of ecosystem services. Development of an ecosystem service supply and use account in the Netherlands is ongoing.

Map of ecosystem assets (the Netherlands)



Source: Statistics Netherlands (CBS) and Wageningen University and Research (WUR) (2016).

3.7. Key research issues in delineating spatial areas for ecosystem accounting

3.82. Approaches to delineating spatial areas for ecosystem accounting are still under development. There are four key research issues that can be identified in that regard.

3.83. First, fundamental to ecosystem accounting is the classification of EAs to ET classes. Currently, definitive advice on the choice of classification, and the associated level of detail, cannot be provided. At the start, countries should seek, as far as possible, to use relevant country-specific classifications, as they will reflect the local situation. At the same time, ongoing research and discussion are needed to establish ET classifications that support cross-country comparison and embody the principles of ecosystem accounting.

3.84. Second, while the framework including EAs, ETs and EAAs has been developed in the context of terrestrial areas, there have been a range of studies applying ecosystem accounting: (a) to coastal and marine areas, including in South Africa (Driver and others, 2012), Canada (Statistics Canada, 2013), Mauritius (Weber, 2014b), the United Kingdom (Office for National Statistics, 2016) and Australia (Australian Bureau of Statistics, 2015)); and (b) to river and freshwater systems, including in South Africa (Driver and others, 2012), Canada (Statistics Canada, 2013) and Australia (Eigenraam, Chua and Hasker, 2013). Indeed, the importance of accounting for marine areas is well recognized. Further research is therefore required to give full consideration to the spatial framework in those contexts.

3.85. There are two specific challenges in that regard: (a) to integrate the linear (usually vector-based) data sets generally required for accounting for rivers with the data sets required for terrestrial ecosystems; and (b) to achieve an understanding of, and to include in the accounts, the interactions between terrestrial systems and river flows, as reflected in, for example, the variation in water flows throughout the year stemming from seasonality and extreme events, and exchange of nutrients between river and terrestrial ecosystems.[23] Challenge (b) has been addressed in a range of hydrologic modelling initiatives, but efforts have seldom been pursued at a scale (e.g., nationwide) commensurate with the scales typically considered in accounting.

3.86. Third, further research is needed on how to appropriately incorporate information related to certain specific ecological entities and elements, including soil resources and their properties, linear features, such as hedgerows and roads, and subterranean ecosystems, such as caves and groundwater systems, as well as areas not currently within the scope of ecosystem accounting, such as the atmosphere and air sheds. A question that might be considered is whether the atmosphere could be included in SEEA EEA as an ecosystem type inasmuch as it would require vertical rather than horizontal delineation. Interactions between the atmosphere and other ecosystem types can in principle be quantified, but as of yet there have been no examples of testing in this context.

3.87. Fourth, the delineation of spatial areas, as well as the compilation of the condition and physical ecosystem services supply and use accounts, may entail the use of remote sensing data, including satellite Earth observation data. Where there is an agreed national land-cover map, it should be utilized. Increasingly, such data have become available for free to all from the Moderate Resolution Imaging Spectroradiometer (MODIS), characterized by medium spatial resolution, since 2000, and high temporal frequency and including derived products such as land cover, vegetation dynamics and net primary productivity; Landsat, with several bands available at 30-metre grid, since 1984, but with lower temporal frequency; and, recently, Sentinel, including the Sentinel-1 radar sensor and the Sentinel-2 optical sensor, with grid size of 10 metres for some bands of the optical sensor.

3.88. For each of those sources of satellite data, there is a dedicated website from which images can be downloaded. Most MODIS and Landsat images and products can be accessed from the EarthExplorer website of the United States Geological Survey.[24] On the other hand, processing and interpretation of images is required if the available products are not sufficient; and such issues as cloud cover (associated with optical sensors) need to be dealt with. Further, there is a related challenge stemming from uncertainty with regard to spatial interpretation and the need for validation and ground truthing of the classified land cover, estimated net primary productivity and other map products. While those challenges are not unique to ecosystem accounting, the importance of efforts to develop and test methods for adapting remote sensing data to ecosystem accounting purposes is clearly unique to this field.

[23] Some discussion of these issues is provided in SEEA-Water (United Nations, 2012b, in particular chap. VII) with respect to the measurement of water quality.

[24] See https://earthexplorer.usgs.gov.

Chapter IV
Ecosystem condition accounts

Key points

- As stated in paragraph 2.35 of SEEA EEA: "the ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics". Measurement of the ecosystem condition is a central facet of ecosystem accounting since it provides information on the capacity of ecosystems to provide ecosystem services into the future.
- In general terms, ecosystem condition is measured by collating indicators for various characteristics of different ecosystem types. Within that broad frame, there are different approaches to the measurement of condition, ranging from more aggregated to more detailed.
- Generally, the development of indicators for characteristics related, for example, to vegetation, water, soil, biomass, habitat and biodiversity for different ecosystem types, as well as indicators of relevant pressures and drivers of ecosystem change, will be appropriate.
- Condition metrics are well established for some of the characteristics of certain ecosystem types, although further testing is required to assess their use for ecosystem accounting. In other cases, the basis for selection and measurement of relevant characteristics is less established, making measurement more difficult.
- A key challenge for ecosystem accounting entails developing a full coverage of measures in a manner that supports aggregation and comparison. In particular, the establishment of composite indicators that integrate various parameters for the condition of different ecosystem types and ecosystem assets poses a core challenge.
- Reference condition approaches offer one technique for developing measures that can be monitored over time and compared across ecosystem types and across countries. However, establishing reference conditions for multiple ecosystem types and more than one country is not a straightforward task; hence, further testing of relevant approaches for ecosystem accounting is required.
- Taking advantage of existing monitoring and research is essential if work on ecosystem condition measurement is to advance. Experts on the subject of local ecosystems should be engaged to ensure the relevance of selected metrics.

4.1. Introduction

4.1. In SEEA EEA, the general and ambitious aim in accounting for ecosystem condition is to bring together the relevant pieces of information needed to provide an overall assessment of the state or condition of various ecosystems in the ecosystem accounting area. According to SEEA EEA (para. 2.35), the "ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics".

4.2. The ecosystem condition account captures, within the framework of a set of key indicators, the state or functioning of the ecosystem in relation to both its ecological condition and its capacity to supply ecosystem services. The ecosystem condition account is complementary to environmental monitoring systems in the sense that, in organizing aggregated high-level information and indicators for an ecosystem accounting area, it typically integrates information from various environmental monitoring systems (on biodiversity, water quality, soils, etc.). The intention of the ecosystem condition account is therefore to build upon rather than replace information from various monitoring systems. Compiling a comprehensive condition account is also likely to require collection and analysis of additional data (e.g., from remote sensing images) and extrapolation or interpolation of existing data.

4.3. The main benefit of compiling an ecosystem condition account stems from the integration of various sets of information on ecosystem condition and from the potential of the ecosystem accounting framework to subsequently combine that information with information on ecosystem services flows and the monetary value of ecosystem assets. That integrated approach—based on a common understanding of the size, composition and types of ecosystem assets—offers insight into changes in ecosystems that is more comprehensive than that provided by individual data sets, which facilitates the expansion of the use of environmental information for policy-related purposes.

4.4. In the compilation of ecosystem condition accounts, a minimum, partial or fully spatial approach can be pursued. In a minimum spatial approach, condition indicators are compiled, aggregated and reported for the individual ETs within the EAA. To a limited degree, spatial variability can be indicated by inserting minimum and maximum values and standard deviations in tables; however, this approach does not allow assessment of condition at specific locations within the EAA. In the partial spatial approach, some of the condition indicators may be spatially analysed and combined with non-spatial indicators, and aggregated indicators may be reported by ET or for administrative units. In a fully spatial approach, condition indicators are comprehensively mapped, so as to provide values of condition indicators for each EA; and accounting tables and maps are produced for all or the majority of indicators so that spatial differences in the ecosystem condition of EAs can be reflected in the accounts.

4.5. Indicators in the ecosystem condition account reflect the general ecological state of an ecosystem, its capacity to supply ecosystem services and the relevant trends, and they may also reflect such characteristics as the occurrence of species, soil characteristics, water quality and ecological processes (e.g., net primary productivity). The indicators selected should be relevant for policy- and decision-making by reflecting, inter alia, policy priorities (e.g., preservation of native habitat); pressures on ecosystems (as measured, e.g., by deposition levels of acidifying compounds versus critical loads for such compounds); or the capacity of ecosystems to generate one or more services (e.g., ecosystem attractiveness conducive to tourism). Generally, different ecosystem types require different indicators. For example, condition indicators relevant for forests are less relevant for cropland.

4.6. Basic spatial or non-spatial information about ecosystems, which is commonly needed for the measurement and modelling of ecosystem services supply, are not among the highest priorities for a basic condition account. For example, to model erosion risks and the ecosystem service of erosion control, information is needed on, among other things, rainfall, slope, slope length and soil type for relevant ecosystem assets. However, inasmuch as these indicators reflect ecosystem characteristics that do not generally change rapidly over time, they cannot be considered key indicators of the changing condition of an ecosystem. Nonetheless, since the collation and organization of such information are likely to constitute an important facet of the development of a complete database for ecosystem accounting, the information can be included in annexes to the ecosystem accounts.

4.7. Since the release of SEEA EEA, a broader context for the measurement of ecosystem condition has been provided by discussions in which several issues were highlighted.

4.8. First, the relevance of ecosystem condition indicators depends upon context, which implies, in part, that the assessment of condition should take into consideration the specific characteristics of the EAA, including the ETs that are present and their composition and the likely uses of EAs (data availability and the possibility of obtaining supplementary data are additional factors to be considered in selecting condition indicators). The testing required to determine the appropriate set of characteristics is therefore a particularly important task in ecosystem accounting. Recent discussions emphasize that it should be possible to provide additional guidance related to the broad areas (e.g., habitat, pressures and drivers, and biological responses) to be covered by a set of indicators (see box 4.1), but this requires further discussion within an accounting context.

4.9. Second, the types of indicators to be considered in the measurement of ecosystem condition may include those that reflect the pressures being exerted on ecosystems, including by air emissions, water effluents and solid wastes. Those pressures may affect economic activities as well as the condition of ecosystem assets.

4.10. Third, in some cases, compilation of composite indicators may be useful. That is a process through which a range of indicators are combined to reflect different elements of ecosystem condition. However, once a suitable set of indicators has been determined, there is no natural a priori procedure for weighting the indicators that could be used to estimate the overall condition of an ecosystem asset: measuring overall condition requires a perspective on the relative importance of the various ecological processes involved, or the various uses of an ecosystem asset. While it is possible to assign equal weight to each indicator, this does not resolve the underlying issue. Alternatively, weights may be determined based on surveys of ecosystem users.

4.11. It is often useful to compare the assessment of actual or current condition using individual or composite indicators with an assessment of benchmark or reference condition. That approach is discussed at greater length later in this chapter. Condition may also be measured using specific classes to allow assessment against standard criteria. That is sometimes carried out with classes reflecting different levels of soil fertility or suitability of land for a specific purpose.

4.2. Different approaches to measuring ecosystem condition

4.12. Any one of three broad measurement approaches can be implemented for use in compiling ecosystem condition accounts. All three represent feasible ways forward for the measurement of ecosystem condition. Further, each of these measurement approaches can be implemented using a minimum, partial or fully spatial approach. Testing is required to determine whether there are significant differences in the results obtained through the use of the different approaches and which of the approaches would be most appropriate for ecosystem accounting purposes. That issue is discussed further in section 6.5.[25]

4.13. The first is an aggregate approach through which indicators for a small set of ecosystem characteristics generally applicable across a country are combined to create a measure of overall condition. Formation of the overall measures requires the application of assumptions on the relative importance of each characteristic and the correlations among them. That approach has been adopted for the *Ecosystem Natural Capital Accounts: A Quick Start Package* (ENCA-QSP) (Weber, 2014a) where indica-

[25] See, also, reflections on the measurement of ecosystem condition within the Knowledge Innovation Project on an Integrated System for National Capital and Ecosystem Services Accounting in the European Union (KIP INCA) (La Notte and others, 2017a).

tors for carbon, water, biodiversity and ecosystem potential are measured for all ecosystem types in a country (or other EAA) and then combined to form a single index, the ecosystem capability unit (ECU).

4.14. The second is a detailed approach through which various characteristics are determined for different ecosystem types. That is the approach that has been used in South Africa (see Driver and others, 2012; Nel and Driver, 2015); in Canada for the measuring ecosystem goods and services (MEGS) project (see Statistics Canada, 2013); in Norway for the development of the Nature Index (see Certain and others, 2011); and in Australia by the Wentworth Group of Concerned Scientists (see Sbrocchi and others, 2015).[26] While, in theory, it may be possible to combine the various indicators of the various characteristics to provide aggregate measures of condition, that step is generally not taken. It is perhaps the Wentworth Group of Concerned Scientists (Australia) through its development of the environmental condition index (Econd) as a reference condition-based indicator and the Norwegian Environment Agency through its development of the aggregate indexes of the Nature Index that have come closest to taking that step. The naturalness of the ecosystem is one of the characteristics considered in defining the reference condition under this approach.

26 It should be noted that the ENCA-QSP approach also supports the use of additional indicators extending beyond an initial standard set.

4.15. The third approach, which is a variation of the detailed approach, entails selecting the condition indicators on the basis of their direct link to the basket of ecosystem services for a given ecosystem asset, taking into account factors such as proximity to populations and land management and use. That approach, which has been used in the development of natural capital accounts in the United Kingdom (see Office for National Statistics, 2017), is related to the concept of ecosystem capacity (see sect. 7.3). Measurement of ecosystem capacity reflects the ability of an ecosystem asset to continue to produce a given service, which is a function of ecosystem condition. Under that approach, condition indicators that can be used to assess ecosystem capacity should be selected (see chap. VII).

4.16. While any one of the three approaches can be adopted for the measurement of ecosystem condition as conceptualized in SEEA EEA, they differ slightly with regard to their interpretation of the concept of condition. The interpretation can, for example, have a strongly ecological slant, or it may also take into account non-ecological factors, such as environmental pressures and indicators related to ecosystem use. While the interpretations adopted along that continuum all recognize the importance of ecological characteristics, they will lead to the selection of different characteristics and indicators. A key area of ongoing research and discussion relates to the selection of ecosystem characteristics appropriate for the measurement of condition for accounting purposes.

4.3. Ecosystem condition accounts

4.17. A central function of ecosystem accounting is to organize biophysical information on the condition of ecosystem assets within an EAA. Table 4.1 presents an example of an ecosystem condition account compiled in physical terms using a variety of indicators for selected characteristics. The table lays out the account's fundamental structure, which provides the basis for organizing relevant indicators by ecosystem types and for distinct points in time (i.e., opening and closing of the accounting period).

4.18. In practice, the indicators in the rows can be defined on the basis of a continuum of information comprising five levels, as explained in section 4.4.2 (especially para. 4.40). Accordingly, the row entries in table 4.1 may be individual indicators or aggregations of indicators for individual ecosystem characteristics. For example, accounting for soil condition may require information on texture, nutrients, pH, soil organic matter content and other factors, with each of the indicators being recorded in the table. Alternatively—again, by way of example—indicators (e.g., pH, turbidity and oxygen content levels) for an ecosystem type (e.g., inland water body) and a related characteristic (e.g., water quality) may be combined to form a single indicator. It should be noted (although this is not shown in table 4.1) that the condition account may also include indicators reflecting human pressures and non-ecological factors.

4.19. Generally, those accounts should be compiled by ET,[27] since each ET (tree-covered areas, grasslands, mangroves, etc.) possess distinct characteristics that should be taken into account when condition is being assessed. That approach also reflects a recognition of the fact that much information on ecosystem condition is available by ecosystem type rather than within the context of broader, landscape-type scales or administrative boundaries. Consequently, the measurement of condition through the harnessing of available scientific information and expertise may be achieved more readily through a focus on ETs.

[27] In table 4.1, SEEA Central Framework land-cover classes are used as proxies for ETs.

Table 4.1
Example of a potential ecosystem condition account

			Proxy ecosystem type (based on land cover)														
Ecosystem characteristics	**Condition indicators (examples)**		Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and intertidal areas	Sea and marine areas
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Vegetation	Native cover	Opening condition															
		Closing condition															
Water quality	Turbidity, pH	Opening condition															
		Closing condition															
Soil	Erosion, pH, nutrients	Opening condition															
		Closing condition															
Carbon	Net primary productivity	Opening condition															
		Closing condition															
Biodiversity	Species richness	Opening condition															
		Closing condition															
Habitats	Fragmentation	Opening condition															
		Closing condition															
Overall condition index		Opening condition															
		Closing condition															

4.20. The ecosystem condition account in table 4.1 is structured to enable the recording of information at two points in time, that is, it presents information on the condition of various ecosystem types at the opening and closing of the reference accounting period (e.g., one year). Ecosystem condition accounting is particularly useful when accounts are developed for multiple years in order to record trends and/or changes in ecosystem condition, and, as relevant, the spatial variability of these trends. It may be that information on ecosystem condition is available for specific years or for specific periods within a year. Updates on some aspects of ecosystem condition can in principle be made with greater frequency (e.g., monthly), and the increasing availability of processed remote sensing data facilitates such regular updates. At the same time, different policy purposes may require information at different temporal resolutions and in some cases, ideally annual, updates may be sufficient for monitoring long-term trends.

4.21. Underpinning these accounts is information from a variety of sources; and, in some cases, source data—including information on land cover, water resources, nutrients, carbon and species-level biodiversity—may themselves be organized in accordance with accounting approaches. Accounts focused on those subjects are discussed in chapter IX. However, recording information on the same topic in different accounts does not give rise to double-counting. For instance, species diversity measures may be relevant in the compilation of both biodiversity accounts and ecosystem condition accounts, and the abstraction of water is relevant to estimation of the supply and use of ecosystem services, as well as to changes in the stock of water resources.

4.22. There are, overall, a range of measurement issues and challenges associated with the compilation of ecosystem condition accounts. Indeed, it is reasonable to conclude that there is still much to be learned about the structure and compilation of those accounts. Particular issues concern the selection of characteristics for various ecosystem types, the relevant indicators for various characteristics, the potential for deriving an overall measure of condition for a single EA by aggregating across various characteristics, the aggregation of condition measures for ETs, recording condition measures that are relevant for combinations of ETs (e.g., measures of fragmentation and connectivity), the level of spatial detail required, and the approach to recording changes in ecosystem condition over time. The following sections provide a discussion of those issues.

4.4. Developing indicators of individual ecosystem characteristics

4.4.1. Selecting indicators

4.23. SEEA EEA describes a number of different ecosystem condition characteristics and associated indicators (see, for example, table 2.3). The development of indicators to assess the condition of particular ecosystem types for specific purposes is a relatively well-established area of research. Bordt (2015a) provides a thorough assessment of the indicators in SEEA EEA and describes several other indicators that may be considered.

4.24. Often, for a given characteristic, the relative importance of the various factors can be weighted, based on the guidance provided in the research, so as to yield an appropriate composite index. The challenge is to determine not whether indicators of specific characteristics of ecosystem condition can be measured, but rather, which characteristics are relevant and how the indicators may be combined.

4.25. If a fully spatial approach to ecosystem condition accounting was adopted, then, ideally, information on each characteristic selected could be measured or downscaled to the BSU level. In many cases, that may be possible and, indeed, for some ecosystem characteristics, such as those pertaining to soil retention and water flows, there may be significant spatial variability that should be considered.

4.26. However, there are some situations in which downscaling may make little sense conceptually or may entail inappropriate downscaling-related assumptions. For example, in measuring ecosystem condition for its suitability in providing habitats, measures of fragmentation and connectivity are likely to be highly relevant. Those characteristics are conceptualized and measurable at the level of multiple ecosystem assets. Attribution of information on fragmentation and connectivity to the BSU level may be possible, but the information remains meaningful only at broader scales. Further investigation of the effects of scale on the measurement of condition for ecosystem accounting is required.

4.27. There are indicators of a certain type, which, while not considered in SEEA EEA, should be given further consideration, namely, functional indicators, for example, of ecosystem resilience and integrity. Functional indicators include indicators of physical and biological ecosystem properties that reflect an ecosystem's resilience to extreme events (for an overview, see Carpenter and others (2010)). If, through scientific research, a functional indicator was established that accorded well with the concept of ecosystem resilience, then such an indicator could be applied directly to particular ecosystem types or might highlight the characteristics that should be the focus of condition measurement.

4.28. While a large number of indicators of coral reef condition, for example, have been used in various monitoring and research programmes, the indicator "percentage live coral reef" is considered a good aggregate indicator for coral reef condition. Even if other types of information may be needed for site-specific coral reef management, that indicator may still be useful in conveying overall trends in reef condition for an EA or ET. Where appropriate and where data are available, that indicator could be supplemented with a limited number of other condition indicators—indicators of, for example, the presence or abundance of fish or other species, which thereby reflect habitat quality or ecosystem functioning or are correlated with ecosystem services (e.g., fisheries or recreation).

4.29. Generally, however, given data limitations, as well as from a conceptual perspective, individual functional indicators are unlikely to be broadly applicable to the variety of ETs within the scope of ecosystem accounting. Instead, it is more likely that ecosystem condition accounts can provide an organizational structure for information relevant to the derivation of functional indicators for different ETs within a country.

4.30. It is not expected that the measurement of condition for each ecosystem type may require the inclusion of a vast number of characteristics. From an ecosystem accounting perspective, the aim is to provide a broad indication of the level of and change in condition rather than to fully map the functioning of every ecosystem asset. In that regard, a key element of accounting is the monitoring of change over time, which signifies the importance of focusing on those characteristics that reflect changes in ecosystem condition. Based on evaluations of the various projects described earlier in this section, it seems that for most ecosystem types, a set of between four and eight indicators can provide the body of sound and robust information needed to assess the overall condition of an ecosystem asset.

4.31. Selection of an indicator should be based on the following five criteria: (a) the degree to which the indicator reflects the overall ecological condition of the ecosystem or key processes occurring within it and is able to signal changes in that condition; (b) the degree to which the indicator can be linked to measures of potential ecosystem services supply; (c) the ease with which policymakers and the general public can understand and correctly interpret the indicator; (d) data availability and scientific validity of measurement approaches for the indicator; and (e) the possibility of generating new data cost-effectively. It is to be noted as well that ecosystem condition, in general, be linked more strongly to potential as opposed to actual ecosystem services supply, since the latter depends on the extent of ecosystem use by people.

4.32. The potential in that area is demonstrated in box 4.1, which is based on research conducted in South Africa. Its accompanying table presents examples of indicators of ecological condition for various ecosystem types.

4.33. With regard to data sources, they vary depending on the indicator selected. Chapter VII introduces a range of potential data sources for the areas of carbon, water and species-level biodiversity monitoring. The publication *Ecosystem Natural Capital Accounts: A Quick Start Package* (Weber, 2014a) lists many data sources in those areas. In a wide variety of cases, satellite-based data are likely to be useful, especially for their breadth of coverage across various ecosystem assets, which is required for ecosystem accounting purposes.

4.34. Compilers are encouraged to consider the research papers and testing outcomes related to various projects and, most importantly, to engage with national experts on ecosystems and biodiversity measurement. It should be noted that different experts may be associated with different ecosystem types. Testing could commence with forests, a particularly suitable ecosystem type, given their importance in many countries and the significant literature on the measurement of forest characteristics (e.g., dominant species, density and canopy cover, biomass and carbon stock).

4.35. Another starting point could be discussions with experts involved in national reporting on the state of and trends in biodiversity within the framework of the Convention on Biological Diversity. Other international initiatives on ecosystem monitoring and measurement are also relevant, including information-collection programmes for monitoring the Sustainable Development Goals and the Global Earth Observation System of Systems (GEOSS) data-collection programme (e.g., within the Earth Observations for Ecosystem Accounting (EO4EA) initiative).[28] In Europe, projects such as Mapping and Assessment of Ecosystems and their Services (MAES); activities pursuant to directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora ("habitat directive"), adopted by the Council of the European Union on 21 May 1992; and Copernicus (the European Union Earth Observation Programme) provides relevant information. Overall, it is the ecosystem condition account that is likely to be the primary account through which engagement with the ecological community can be fostered.

28 See https://www.earthobservations.org/activity.php?id=111 and https://www.earthobservations.org/geoss_wp.php.

Box 4.1

Proposals for indicators of ecological condition in South Africa

The approach proposed in South Africa for recording ecological condition draws on experience in developing ecosystem condition accounts for river ecosystems in that country, which was then applied to other ecosystem asset classes (see Nel and Driver (2015) for details).

Some key points related to the proposed approach are as follows:

- For each broad class of ecosystem assets (e.g., terrestrial, river, wetland, coastal, marine), from four to six indicators of ecological condition are measured on a scale of 0 to 1 (or 0 to 100). These are aggregated to produce an overall index of ecological condition. Examples of possible indicators for assessing ecological condition in terrestrial and river ecosystems are given in the tables below.
- Indicators of ecological condition should reflect a combination of:
  - Ecosystem pressures (drivers) in the class of ecosystems concerned, such as land cover/land-use change in terrestrial systems, hydrological changes in freshwater systems, harvesting pressure in marine systems;
  - Habitat attributes, such as degree of fragmentation, instream siltation;
  - Biological responses of the ecosystems and associated species, such as changes in population levels of particular species, loss of species richness;
- In the process of developing the condition accounts for a particular class of assets, it is important to draw on the substantive thinking of ecologists in the various areas (terrestrial, freshwater, marine) on how to measure ecosystem condition. It is essential for ecologists to be closely involved in the selection of indicators of ecological condition and in determining the method to be used for aggregating them, so as to ensure that the result is ecologically meaningful and sound;
- It is not possible to create a single set of indicators of ecological condition that applies to all ecosystem asset classes. However, some indicators are likely to be common across more than one asset class. While selection of the set of indicators of ecological condition for a particular asset class may depend partly on data availability, ideally, the process should not be driven at the starting point by that factor;
- All indicators should be assessed/quantified in relation to a reference condition for the ecosystem type concerned. Where possible, the reference condition should be the natural or near-natural condition in the absence of significant modification by human activity. If that is not possible, an alternative stable reference condition can be selected (e.g., condition at a particular baseline date).

Below are examples of what the tables might look like for two different classes of ecosystem assets. The sets of indicators listed are not intended to be exhaustive or definitive. Their function is to help illustrate the approach under consideration here.

Examples of possible indicators for assessing ecological condition in terrestrial and river ecosystems

(a) Terrestrial ecosystems

Ecosystem type (examples)	**Ecosystem characteristic (e.g., ecological condition indicators)**				**Overall ecological condition index**
	Habitat/land use (e.g., loss of natural vegetation, density of invasive species, quantity of irrigation, quantity of fertilizer, density of livestock)	**Fragmentation** (there are many possible ways to measure fragmentation)	**Soil** (e.g., extent of erosion by gullies and rills, sediment loss or accumulation, soil chemistry (pH, salinization), extent of tillage)	**Species** (e.g., loss of keystone species, loss of palatable species, reduced populations of harvested species, loss of species richness)	
Savannah					
Forest					
Desert					
…					

(b) River ecosystems

Ecosystem type (examples)	**Ecosystem characteristic (e.g., ecological condition indicators)**					**Overall ecological condition index**
	Hydrology (e.g., quantity, timing, velocity of flow)	**Water quality** (e.g., pH, turbidity, electrical conductivity, levels of phosphorus/nitrogen/oxygen	**Instream habitat** (e.g., sediment overload, channelization, temperature changes)	**Riparian habitat** (e.g., bank stability, loss of natural vegetation, density of invasive alien plants in riparian buffer)	**Species** (e.g., loss of sensitive species, loss of species richness, reduced populations of harvested species)	
Mountain streams						
Foothill streams						
Lowland rivers						
…						

4.4.2. Aggregate measures of condition

4.36. In ecosystem accounting, where indicators of individual characteristics are available, the question then becomes whether an aggregation of indicators is required in order to obtain overall measures of ecosystem condition for a single ET and for multiple ecosystem assets within an EAA. As noted in the introduction to the present section, the development of overall measures of the condition of ecosystem assets remains a challenge in measurement terms.

4.37. When aggregation is considered in ecosystem accounting, a primary objective is to provide decision makers with macro-level information which supports an understanding of the state of various ecosystems relative to each other as well to reference conditions. Usually, there is a limited set of resources available to enhance ecosystem condition; hence, choices must be made across a range of investment options. Ideally, macro-level information would give a sense of the overall condition of each ecosystem relative to other ecosystems (i.e., based on the comparison of EAs and ETs in different locations), as well as to relevant thresholds and limits. It is recognized that description of those thresholds and limits also requires specialist ecological knowledge.

4.38. However, care must be taken to ensure, especially in the early stages of ecosystem condition account development, that uncertainties and limitations are properly communicated to the users of the accounts. Indeed, it is likely that in the near future, the level of detail of the condition accounts will be insufficient for those accounts to serve as the sole source of information for decision-making. Hence, the accounts will be only a starting point for discussion of site-specific resource management questions.

4.39. Movement along the information continuum from individual indicators of specific characteristics to information on relative overall condition entails an increase in the information and assumptions required. In general terms, as the number of ecosystem types increases, making comparisons is likely to become more difficult. It should be noted that further testing will be required before more specific guidance can be given, in particular on points (a) to (c) in paragraph 4.40 below.

4.40. The continuum encompasses five levels:

(a) At the first level, information on individual characteristics can be measured directly. For example, both the alkalinity/acidity of soil and the biomass of a forest can be measured in absolute terms. Examining those measures over time can provide information on the ecosystem's condition;

(b) At the second level, it may be necessary, for some characteristics, to compare the chosen metric with a known baseline, standard, threshold or limit, in order to make some inferences regarding ecosystem condition. For example, measures of water or air quality rely on both direct measures of pollutants and comparison of the observed measure with a relevant standard;

(c) At the third level (still for a single characteristic), through the formation of a composite indicator, a number of indicators can be weighted together. For such a composite indicator to be meaningful, it would need to be measured or interpreted in relation to a common baseline or standard. It is to be noted that, measurement at the first three levels of many characteristics for specific ecosystem types is an area that is well developed in the literature;

(d) At the fourth level, the goal is to use, for a specific ET, a combination of indicators in which each indicator is associated with a different characteristic. Achieving the goal entails two steps: (i) selecting the characteristics that have been discussed in the previous section and (ii) establishing the means of combination. For the second step, SEEA EEA suggests the use of a reference condition, which would enable indicators for each characteristic to be compared with the same reference condition for that ecosystem;

(e) At the fifth level, assuming that measures of ecosystem condition have been established for each ET (i.e., at level four), it is necessary to find a means of comparison across different ecosystem types. Again, the use of reference conditions is a possible way forward where, in this case, all ETs are compared with a single reference condition. However, establishing a reference condition applicable to all ecosystems in a country is a major challenge from both a conceptual and a data perspective. One potential option is to select a specific year as the basis for a reference condition, although selection of any given year is arbitrary to some extent. A further extension at this level would entail comparison of the ETs of different countries.

4.41. Given the desire in accounting for macro-level information, it is the challenges in measurement and interpretation at the fourth and fifth levels that are of particular interest. The extent to which singular reference conditions can be used to make comparisons within and/or across ETs is thus a focus in that regard. The subject is discussed further in section 4.4.3.

4.42. If an appropriate reference condition can be established, the next step would be to normalize each indicator. That is commonly done by assigning the reference condition a "score" of 100 and the actual condition, a score between 0 and 100. A related approach is to grade ecosystems on a scale of A to F or on a similar scale, with A representing the reference condition and F, the condition most distant from the reference.

4.43. Establishing reference conditions and normalizing scores constitute yet another task that should be conducted in close consultation with national experts in the fields of ecosystems and biodiversity. Indeed, it may well be the case that there are bodies of work produced by government agencies, research bodies and universities that can be used or built upon to support that type of assessment. As the use of reference conditions is well documented in the ecological literature, it should be considered for adaptation to ecosystem accounting.

4.44. While using reference conditions is a well-known practice, the process of choosing a reference or benchmark condition for accounting purposes, given the precision required, is a subject for further discussion and testing. SEEA EEA focuses on several conceptual considerations associated with reference condition-related approaches, while Bordt (2015a) considers such approaches more comprehensively. Section 4.4.3 provides a short summary of the issues involved.

4.45. Yet, following the logic outlined earlier in the present subsection, even where each indicator can be compared with an agreed reference condition, a second step remains, namely, to weight together the indicators for the various characteristics. From a statistical perspective, such an ambitious goal is not new, as evidenced by, for example, the construction of the human development index (see United Nations Development Programme, 2014). However, as has been the case for socioeconomic indicators, the best approach to weighting different ecosystem condition indicators is still a matter of debate.

4.46. By far, the easiest solution is to give each indicator equal weight in an overall measure. However, this may not be appropriate from an ecological perspective, given that some characteristics may play a relatively more important role than others. Moreover, equal weighting may not reflect the relative importance of various characteristics in the potential supply of ecosystem services or take into account various thresholds and non-linearities that may apply in aggregating indicators related to different facets of condition.

4.47. An extended discussion on aggregation of ecosystem measures is provided in Bordt (2015b), where a number of options and issues are highlighted. At this stage, no clear pathways forward have emerged, but a number of areas do exist that are suitable for research and testing, which are discussed in section 4.5.

4.4.3. Determining a reference condition

4.48. Determining an appropriate reference condition is not a straightforward procedure and, in fact, can be a matter of considerable debate. The present discussion provides a short summary of the key points in that regard from an ecosystem accounting perspective.

4.49. A common starting point for the determination of a reference condition is the application of the concept of close-to-natural or pristine condition, whereby the reference condition would reflect the condition of the ecosystem asset if it had been relatively unaffected by human activity. In many cases, determination of that reference condition is achieved by selecting a point in time in the pre-industrial stage of a country's development. In Australia, for example, the year 1750 is commonly used.

4.50. A positive feature of that approach is its placement of all ecosystem assets on a common footing, enabling interpretations of the term "distance from natural" to be relatively equivalent for all types of ecosystem. That is, under that approach, it is possible to compare ecosystems that are extremely diverse, such as rainforests, with ecosystems that are much less diverse, such as deserts.

4.51. The question of what constitutes a natural ecosystem, however, can lead to significant debate, particularly in those countries where human influence on the landscape has been evident for thousands of years. Almost all of Europe, for example, may be considered to have been forested at one point in time, but the use of that point as the basis for a reference condition for the current mix of ecosystem types is not likely to be appropriate or useful for decision-making, since most of the landscapes of Europe have been modified by people for thousands of years. Also, as many of Europe's species of fauna and flora have had time to adjust to human management of those landscapes, they would not necessarily benefit from conversion of the landscapes to full forest cover. Moreover, inasmuch as the specific composition of the forest under natural conditions has changed considerably over the last millenniums, the forest ultimately selected to represent natural conditions would always be an arbitrary choice.

4.52. Another concern related to the use of natural reference conditions for ecosystem accounting is that they would not take into account the current use of the ecosystem. Thus, to the extent that the focus of condition measurement is on the potential to supply ecosystem services, assessment of condition in terms of distance from natural does not compare like with like. That is directly linked to the previous discussion on the involvement of ecological and non-ecological factors in the assessment of condition. As the discussion progresses, it must be linked to the issue of defining an appropriate reference condition.

4.53. A related concern is that the reference condition can be mistakenly perceived as a target or optimal condition. In fact, a clear distinction should be made between reference and target conditions. A reference condition should be used solely as a means of estimating current condition relative to the reference condition and comparing condition across ecosystem characteristics and ecosystem types. A target condition, on the other hand, should be developed through participatory processes, taking into account economic, social and environmental factors. For example, in an urban area the actual condition is likely very low—or zero—relative to a reference condition reflecting the previous natural state of that area. Hence, it is inappropriate to suggest that the target condition should be the natural state. A more appropriate target condition in urban areas may be improved air quality through the contribution made by the planting of additional trees. In general, information on the actual and reference conditions presented in ecosystem accounts is expected to serve as a useful input into a discussion on target conditions.

4.54. For accounting purposes, it may be sufficient to use the condition at the beginning of the accounting period as a reference condition and measure the actual condition relative to that point in time. A variation of that approach entails selecting the condition at the point in time at which the accounts commence.

4.55. The difficulty associated the latter approach is the following: an ecosystem that was heavily degraded might be compared, starting from the same point in time, with an ecosystem that has not been degraded at all, that is, both ecosystems would be assigned a reference condition of 100 for the selected point in time.

4.56. On balance, then, selection of a reference condition calls for a careful balance of requirements, as well as the transparency of methods and assumptions. An important consideration in making a decision is the scale of the analysis. In general, the challenge of determining the reference condition becomes greater as the scale of analysis increases, since in this case the number of factors to be taken into account increases as well. On the other hand, if the intent is to measure the condition of only one characteristic (e.g., soil condition) of a specific ecosystem type (e.g., open grasslands), then the reference condition may be selected taking only that characteristic and ecosystem type into account.

4.57. However, when the goal is to compare multiple characteristics and multiple ecosystems, what should serve as the relevant single reference condition may not be readily apparent. For some countries, an appropriate reference condition may be established through use of a point in time in the not-too-distant pre-industrial past, yielding a more or less common understanding of change with respect to that reference condition. But, as already noted, such a choice is likely inappropriate when the current landscape mix of ecosystem types has, to varying degrees, been evident for centuries, in which case the pre-industrial reference condition reflects only ecological characteristics.

4.58. However, even if a national-level reference condition can be established, a challenge still remains, namely, to find one that allows for comparison across countries. Given the diversity of landscape development patterns, that challenge cannot be taken lightly.

4.59. Pending further testing of different approaches to defining reference conditions, it is recommended, in the development of ecosystem condition accounts for a given country, that a point in time be selected as far in the past as possible, given the availability of data, to facilitate the development of the relevant metrics of current condition and the application of the reference condition approach. That is a pragmatic starting point, particularly for the measurement of change over time within a country, which can support a focus on the direction and strength of trends in condition. It should also help focus discussion on the challenging measurement issues associated with the selection of the indicators and maintaining ongoing time series. Using a relatively distant reference point, rather than the beginning of the accounting period, better supports the assessment of distance from thresholds for ecosystem assets.

4.60. To allow for comparison across countries, it is necessary to move towards common structures for the organization and presentation of data on ecosystem condition. Testing options for common structures that are both meaningful for comparison purposes and capable of implementation is important. Another consideration with respect to testing for a country is the potential for use of one reference condition domestically and of a different reference condition for international comparison.

4.5. Recommendations for compiling ecosystem condition accounts

4.61. The measurement of ecosystem condition in accordance with the concepts underpinning the ecosystem accounting model is a complex task, stemming from the need to consider multiple ecosystems and multiple characteristics. At the same time, research findings in the general area of condition measurement are sufficient to suggest that the testing of different approaches in ecosystem accounting projects is highly feasible and should therefore be pursued.

4.62. An initial question in taking this work forward is how spatially variable indicators can be aggregated both within and between ecosystems. For example, while soil nutrient concentration may be highly relevant as an indicator of soil fertility and thus of ecosystem condition and may have important repercussions for potential ecosystem services supply, aggregating this indicator is difficult. The average soil nutrient concentration for an area is meaningless, since, theoretically, it may include 50 per cent of the area with very few soil nutrients and 50 per cent of the area with an excess of nutrients. Therefore, classification (e.g., of soil fertility level) or comparison with reference conditions (in order to measure, e.g., deviation from non-degraded nutrient content) may be required.

4.63. Approaches to aggregation over space, time and ecosystem types depends upon policy-related factors, data availability and the required accuracy of the condition account. It is recommended that the account be developed stepwise. The first step is to set up the account for specific ETs, using a set of selected indicators. Over time, the account can be broadened in scope and expanded to include a larger range of indicators.

4.64. At each step, the indicator's scientific validity, the ease with which it can be understood, and the availability of data should be considered. Some general recommendations, including steps for the measurement of condition, are as follows:

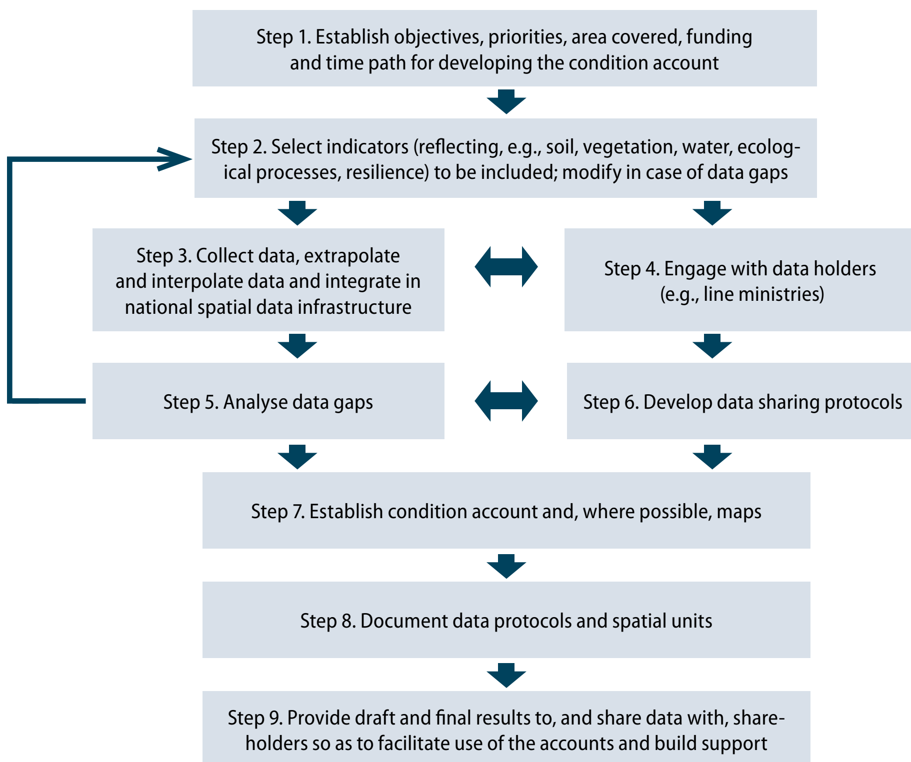
- Select a minimum, partial or fully spatial measurement approach, as well as a specific ET as the initial focus;
- Select condition indicators for the main ecological characteristics of the ETs, including vegetation, water, soil, biomass, habitat and biodiversity. Where relevant, condition indicators related to land, water and forests should be compiled following the accounting of SEEA Central Framework (this is linked to the broader role of thematic accounts as discussed in chap. IX of this publication);
- Consider whether indicators reflecting ecosystem integrity can be included (e.g., indicators of fragmentation, resilience, naturalness and ecosystem diversity);
- Consider whether indicators of pressures on ecosystems (or drivers of ecosystem change) should be included in the condition account to support a connection to the supply of ecosystem services;
- Choose an appropriate reference period for the condition measure or, alternatively, use the opening stock;
- Record and report on the variability and sources of error in the data;
- Once steps are completed for an initial ET, repeat the steps for other ETs. Then, consider whether aggregation of indicators across ETs or across the overall EAA is feasible and if it is, compile the aggregate indicators.

4.65. As a means of supporting the comparison of ETs within a country, it is recommended that, where possible, a single reference condition approach be used. Different principles for determining the reference condition can be applied, including the principle of naturalness. However, given that measuring "naturalness" is a practical issue and given the difficulty of applying this principle in a number of countries, it is recommended that, as a starting point for ecosystem accounting, a reference condition at a single point in time be selected. This allows the development of the relevant metrics for current condition and the application of the reference condition approach.

4.66. Throughout the process of development of condition indicators for various ETs, it is important: (a) to maintain a reliable record of data gaps as a basis for engagement with the research community; and (b) to prioritize investments in data.

4.67. On the whole, these recommendations can be tested in applications at country and regional levels. A flow chart depicting the development of the ecosystem condition account is provided in figure 4.1.

Figure 4.1
Compiling an ecosystem condition account



4.6. Ecosystem condition issues for research

4.68. At this stage of the development of ecosystem accounting, the most important work required on ecosystem condition is the testing of the approach described in this chapter and the comparison of experiences across ETs and countries. Testing should be undertaken together with consideration of specific research issues, as discussed in this section.

4.69. Most important, a clearer focus is needed on the extent to which the measurement of condition is to include the use of both ecological characteristics and non-ecological characteristics, including indicators of the environmental pressures exerted on ecosystems. Consideration of this issue would provide much-needed clarity on the relation of the concept of ecosystem condition for ecosystem accounting purposes to the measurement of ecosystem services and to the concepts of ecosystem capacity and ecosystem capability (see chap. VII).

4.70. Given the requirements for conceptual clarity, specific work is needed to identify the condition indicators that facilitate the connection of condition to ecosystems' capacity to supply ecosystem services. That should enable the achievement of a better understanding of information gaps, that is, gaps between the data required to comprehensively monitor ecosystem condition vis-à-vis naturalness and potential capacity to supply ecosystem services, and the data from various sources that is actually available.

4.71. Further research is also required on the reference conditions to be chosen for ecosystem accounting purposes. For specific regions in some countries, use of natural ecosystems as the reference condition may be appropriate. However, it is necessary, more generally, to establish non-natural reference conditions possibly linked to a historical baseline or conditions as prescribed in policies (e.g., on water quality), while taking into account links to the supply of ecosystem services.

4.72. Not only does there need to be a focus on measurement of condition for specific ETs, but also work also remains to be done on defining and incorporating condition indicators applicable at larger scales such as habitat fragmentation or ecosystem diversity. That work should also be seen within a broader context, in which scale effects in the measurement of ecosystem condition and ecosystem services are taken into account.

4.73. The development of overall indices of condition for ecosystem assets—based either on aggregation of indicators for selected characteristics or on some alternative approach, for example, isolation of key characteristics in ecological terms—represents yet another area of research. A spectrum of approaches for aggregation are available, ranging from the use of an equal weight for all indicators, to weighting based on expert judgment. It is also possible to weight indicators: (a) by using specific criteria, that is, based, for example, on ecosystem compartment (soil, vegetation, etc.) or species group (insects, mammals, plants, etc.); or (b) by taking into consideration key ecosystem services.

Chapter V
Accounting for flows of ecosystem services

Key points

- From the perspective of ecosystem accounting, ecosystem services are defined as the contributions made by ecosystems to benefits used in economic and other human activity. It is therefore important to distinguish clearly between ecosystem services and benefits.
- Generally, national-level accounting focuses primarily on final ecosystem services, all of which reflect a direct link between ecosystems and economic units.
- Intermediate ecosystem services are important for understanding relationships and dependencies among ecosystem assets. While those services can be incorporated in the ecosystem accounting model, they are not a priority area for measurement. Further discussion and research focused on accounting for intermediate ecosystem services are required.
- An important aspect of the compilation of estimates of ecosystem services flows is the classification of ecosystem services, through the use, for example, of the Common International Classification of Ecosystem Services (CICES), the Final Ecosystem Goods and Services Classification System (FEGS-CS) or the National Ecosystem Services Classification System (NESCS).
- There are two principal approaches to populating the ecosystem services supply and use account with data. The first approach, starting with data that are already included in the national accounts, identifies the ecosystem contribution to the benefit involved. Subsequent preparation of maps requires spatial allocation of data on ecosystem services.
- In the second approach, which is required for ecosystem services that are not connected to a specific benefit measured in the accounts (this is often the case for regulating services), spatial models or direct measures are utilized to quantify the ecosystem services.
- Construction of the ecosystem services supply and use account requires consideration of the use of ecosystem services by various economic units, including households, businesses and governments.
- In some cases, biodiversity may be considered a cultural ecosystem service but, generally, biodiversity is best regarded as a characteristic of ecosystem assets that can be degraded or improved over time, and that underpins the supply of ecosystem services. It is recorded in the thematic account for biodiversity and as part of ecosystem condition accounts.

5.1. Introduction

5.1. Ecosystem services are the connector—the glue—between ecosystem assets, on the one hand, and economic production and consumption, on the other. Their measurement is thus central to achieving the goal of integrating environmental information fully into the existing national accounts.

5.2. Since the release of *Ecosystems and Human Well-being* (Millennium Ecosystem Assessment, 2005), there has been a significant increase in the number of studies focused on ecosystem services. These studies, in which researchers from a range of disciplines participated, have focused on many aspects of definition and measurement. Through subsequent work within the context of The Economics of Ecosystems and Biodiversity (TEEB) initiative (TEEB, 2010; 2012); the Mapping and Assessment of Ecosystems and their Services (MAES) framework (Maes and others; 2013) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the potential of the ecosystem services approach to foster an understanding of the relationship between humans and the environment has been strengthened. In its attempt of to navigate the various discussions on ecosystem services, SEEA EEA was confronted with a range of choices related to the definition and measurement of those services for accounting purposes. Ecosystem accounting has built upon all this work and research.

5.3. In ecosystem accounting, each ecosystem asset generates a set or basket of final ecosystem services. They are defined as contributions to the production of benefits and encompass a wide range of services provided to economic units (households, businesses and governments). Those services may be divided into provisioning services (related to the supply of food, fibre, fuel and water); regulating services (related to activities of filtration, purification, regulation and maintenance of air, water, soil, habitat and climate) and cultural services (related to the activities of individuals in, or associated with, nature).

5.4. Benefits may be either *SNA benefits*, that is, goods or services (products) produced by economic units (e.g., food, water, clothing, shelter and recreation) currently included in the economic production boundary of the SNA; or *non-SNA benefits*, that is, benefits that accrue to individuals, or society generally, that are not produced by economic units (e.g., clean air). By convention, the measurement scope of non-SNA benefits for ecosystem accounting purposes is limited to the flow of ecosystem services with an identifiable link to human well-being.

5.5. In the accounting system, for each supply of final ecosystem services, there is a corresponding use that leads to the production of either an SNA or a non-SNA benefit. Further, in each sequence of use of ecosystem services and production of benefits, there is an associated user or beneficiary, that is, an economic unit—business, government or household. Thus, every final ecosystem service flow represents an exchange between an ecosystem asset (as a producing/supplying unit in the accounting system) and an economic unit.

5.6. Building on the framing of ecosystem services in ecosystem accounting described in chapter IV, the present chapter encapsulates the main points set out in SEEA EEA concerning those services, introduces refinements to SEEA EEA model and examines the main measurement issues and remaining challenges. The following topics are covered: the ecosystem services supply and use account (sect. 5.2); issues related to the definition of ecosystem services (sect. 5.3); approaches to the classification of ecosystem services (sect. 5.4); the role and use of biophysical modelling (sect. 5.5); and the relevant data sources, materials and methods for measuring ecosystem service flows (sect. 5.6). Practical recommendations for compiling an ecosystem services supply and use table including a flow chart and an example, and selected topics for further research are presented sections 5.7 and 5.8, respectively.

5.2. Ecosystem services supply and use accounts

5.2.1. Introduction

5.7. The ecosystem services supply and use account records the actual flows of ecosystem services supplied by ecosystem types and used by economic units during an accounting period. Ecosystem accounting in general, and the ecosystem services supply and use account in particular, focus on ecosystem services and their connections to the production and consumption of other goods and services. The scope of the ecosystem services supply and use account does not extend to measurement of the broader costs and benefits that may arise from increased or reduced consumption in terms, for example, of health and social outcomes. Hence, ecosystem accounting does not consider the relationship between people and the environment from an economic or social welfare perspective. At the same time, information on the supply and use of ecosystem services as recorded in the accounts is capable of supporting an examination of relevant welfare outcomes (see chap. VI for further discussion on this topic).

5.8. Within the conceptual framework of ecosystem accounting, the supply of ecosystem services is equal to the use of those services during an accounting period, that is, supply is not recorded if there is no corresponding use. While measurement of the potential or sustainable level of supply that could be delivered by an ecosystem asset may be highly relevant, that is not the focus in the supply and use accounts.[29]

[29] The corresponding concepts of ecosystem capacity and potential supply are discussed in sect. 7.3.

5.9. Recording supply as equal to use means that, from an accounting perspective, ecosystem services are considered to reflect revealed transactions or exchanges that take place between ecosystem assets on the one hand and economic units (households, businesses or governments) on the other. It is implicitly assumed that each transaction is distinct and that each ecosystem service is hence separable.

5.10. The data in an ecosystem services supply and use account, which may be compiled in both physical and monetary terms, are related to a given EAA and should be structured by type of ecosystem service (e.g., timber provision, water purification).

5.2.2. Overall structure of the supply and use account

5.11. The structure of the ecosystem services supply and use account is displayed in table 5.1. It is to be noted that the list of types of ecosystem services presented is indicative only, but in due course should reflect an agreed classification of those services. The features of the data recorded in quadrants B, C and E–G and the reasons data are not recorded in quadrants A, D and H are as follows:

- A: records no data, as, in concept, economic units cannot supply ecosystem services;
- B: records the supply of ecosystem services by ET;
- C: is the equivalent of the standard physical supply and use table displaying the supply of products by various economic units. That quadrant reflects the production of benefits to which the ecosystem services contribute. The products encompass all goods and services produced in an economy. The economic units are broken down by type of activity and hence include both private and public sector production;
- D: records no data, as, in concept, ecosystems cannot supply products (i.e., goods and services within the SNA production boundary);
- E: records the use of ecosystem services by type of economic unit, including the use of those services both as input to further production and as final consumption;

Table 5.1
Provisional ecosystem services supply and use account and product flows (physical units)[a]

Ecosystem services supply table																									
		Type of economic unit								**Proxy ecosystem type (based on land cover)**															
	Measurement units	Agriculture, forestry and fisheries	Electricity, gas supply	Water collection, treatment and supply	Other industries	Governments	Households	Accumulation	Rest of the worlds–Imports	Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and intertidal areas	Sea and marine areas	TOTAL SUPPLY
										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Ecosystems services																									
Provisioning services																									
Biomass accumulation																									
Timber																									
Crop																									
Grass/fodder																									
Fish																									
Water abstraction																									
Regulating services					A												B								
Carbon sequestration																									
Water regulation																									
Water purification																									
Air filtration																									
Nutrient/waste remediation																									
Pest and disease control																									
Soil retention																									
Cultural services																									
Enabling tourism and recreation																									
Enabling nature-based education and research																									
Enabling natured-based religious and spiritual experiences																									
Products					C												D								

[a] The types of ecosystem services shown are indicative only.

Ecosystem services use table																									
		Type of economic unit								**Proxy ecosystem type (based on land cover)**															
	Measurement units	Agriculture, forestry and fisheries	Electricity, gas supply	Water collection, treatment and supply	Other industries	Governments	Households	Accumulation	Rest of the worlds–Exports	Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and intertidal areas	Sea and marine areas	TOTAL SUPPLY
										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Ecosystems services (detail corresponding to supply table)																									
Provisioning services																	**F**								
Regulating services					**E**																				
Cultural services																									
Products					**G**												**H**								

- F: provides the opportunity to record intermediate ecosystem services, that is, services supplied by EAs and used by other EAs. If those flows were to be recorded, then the scope of the supply of ecosystem services recorded in quadrant B would need to be equivalently larger (intermediate services are discussed further in sect. 5.3);
- G: is the equivalent of the standard physical supply and use table showing the use of products by different economic units;
- H: records no data, as, in concept, ETs cannot use products.

5.12. The structure of the ecosystem services supply and use account incorporates flows of products. That supports the joint presentation of data on both the ecosystem services used by economic units, and the products (SNA benefits) to which those services contribute. The output of products such as livestock would be recorded in the first column of quadrant C (under agriculture) and the use of ecosystem services (e.g., grass consumed directly by livestock) would be recorded in the same column in quadrant E. The original supply of those ecosystem services would be recorded in quadrant B. If desired, inputs of products such as fertilizer or veterinary costs could be recorded in quadrant G. Consequently, key elements of a production function that includes ecosystem services as inputs could be recorded in each column pertaining to a type of economic unit.

5.2.3. Connection to SEEA Central Framework

5.13. While the basic structure of the account is derived from the design of physical supply and use tables in SEEA Central Framework, there are three principle alterations. *First*: unlike the Central Framework physical supply and use tables, which contains just one column representing the environment, the ecosystem services supply and use account contains multiple columns, each representing an ET.

5.14. *Second:* the physical supply and use tables presented in SEEA Central Framework covers three types of flows: natural inputs, products and residuals. While, in concept, ecosystem services align generally to natural inputs, in the Central Framework, coverage is limited to provisioning services; hence, there may be differences in the descriptions of the flows, compared with the descriptions found in the Central Framework, to be considered. Regulating and cultural services are excluded from the Central Framework. It is to be noted, however, that, some regulating services are related to flows of residuals recorded in the Central Framework (e.g., emissions, pollution, waste). For example, there is a connection between residual flows of air pollutants and air filtration services. Conceptually, however, those are different flows.

5.15. *Third:* SEEA Central Framework does not consider the ways in which different environmental assets may be connected that is, it incorporates an individual-resource perspective. In contrast, the ecosystem services supply and use account has the capacity to record intermediate services reflecting the dependencies existing between ecosystem assets. That is therefore a feature unique to ecosystem accounting.

5.16. In line with SEEA Central Framework, ecosystem services are recorded before deducting any natural resource residuals.[30] Thus, in the case of timber harvesting, for example, the biomass that is felled represents the quantity of the ecosystem service, just as the biomass felled is regarded as the flow of natural inputs in SEEA Central Framework. However, further work is needed to determine how to define and record flows of natural resource residuals within an ecosystem accounting context.

[30] These residual flows are additional to the residuals related to emissions, pollution and waste mentioned in para. 5.14.

5.2.4. Recording the connection to economic units

5.17. *Economic units and ecosystem assets*: in recording the supply of ecosystem services, it is important to distinguish between economic units and ecosystem assets. Following the ecosystem accounting framework described in chapter II, only ecosystem assets can supply ecosystem services that are subsequently received by economic units. For example, in the case of agriculture- or forestry-related ecosystem services, although an economic unit (e.g., a farmer or forester) may manage the associated ecosystem, for accounting purposes, the farmer and the forester should be seen as using inputs from ecosystem assets (i.e., the ecosystem services) to supply benefits (crops, timber, etc.) that are produced by combining ecosystem services inputs with inputs from other economic units (fuel, fertilizer, etc.).

5.18. Although in table 5.1, the supply of ecosystem services is shown as arising only from ecosystem assets (quadrant B), it may be of interest to attribute the supply of those services to particular economic units. For example, ecosystem services that are inputs to cropping or livestock rearing activities could be considered to be supplied by agricultural businesses that are managing the associated ecosystem asset. This alternative presentation could be recorded in a stand-alone table following the structure of rows and columns used for quadrant A in the table. The recording should be reasonably straightforward for provisioning services; however, it may be more difficult to attribute the supply of some of the regulating and cultural services to specific economic units.

5.19. *Economic units, ecosystem services and residual flows*: SEEA Central Framework records flows of residuals (e.g., emissions, pollution, waste). Residual flows are not ecosystem services: rather, they are physical flows from economic units into the environment. While from a conceptual standpoint, residual flows and ecosystem services are different, there are important relationships between them. Specifically, several regulating services effect the breakdown or absorption of the substances present in residual flows. In that context, these ecosystem services may be regarded as providing "sink services", that is, the ecosystem acts as a sink for or receiver of residuals arising from economic activity.

5.20. From an accounting perspective, the extent of ecosystem services is limited by two factors. First, there must be a related demand for the service, that is, a human must benefit from the breakdown or absorption of the residual substances. For example, when water undergoes river purification through removal of excess nutrients discharged by various economic sectors, a service is supplied only if the water is abstracted for human use downstream, at which point the removal of those nutrients would provide a benefit (e.g., a reduced need for water purification treatment). Second, it may not be possible for the entire quantity of residual substances to be broken down or absorbed in ecosystem processes, in which case the extent of the ecosystem service is limited, reflecting the quantity of the residual substances that are absorbed. On the other hand, the quantities of residual substances that are not broken down or absorbed may be of particular interest with respect to the measurement of environmental pressures, as they are related to changes in ecosystem condition. Overall, information on residuals is related to but different from information on ecosystem services. Given the differences, entries for residual flows and entries for ecosystem services should not be recorded in a single table.

5.2.5. Compiling the ecosystem services supply table

5.21. Attributing the supply of ecosystem services to a specific EA and ET is likely to present a challenge in the compilation of the ecosystem services supply table. While unlikely to be an issue for provisioning services, it may be of concern for regulating services and some cultural services in cases where the service is provided through a combination of EAs within a landscape.

5.22. It is therefore recommended that, as a first step in accounting for ecosystem services, compilers create a table showing which ecosystem services are likely to be supplied from different ETs for their country or target ecosystem accounting area.[31] In undertaking that task, a classification of ecosystem services such as the Common International Classification of Ecosystem Services (CICES), the Final Ecosystem Goods and Services Classification System (FEGS-CS) or the National Ecosystem Services Classification System (NESCS) can be used as a form of checklist (see sect. 5.4).

5.23. It is to be expected that for some ecosystem services, particularly regulating services such as carbon sequestration, the same service will be supplied by more than one ET. Also, for some ecosystem services, the supply of the service will be the result of the combined production of neighbouring ETs.[32] For example, cultural services may be supplied by a mix of ETs (e.g., lakes and wetlands). In those cases, some allocation of ecosystem service flow between ETs is required.

5.24. It would be appropriate for the table described in paragraph 5.22 to be used as a subject for discussion through which to obtain input from various experts, including specialists in the area of specific ecosystem types and/or specific ecosystem services. Moreover, it is important that the development of such a table be informed by the experience of people with an understanding of the link between ecosystems and economic and human activity. That should ensure that commonly overlooked services, particularly various regulating services, are not ignored. The initial table could also serve as a basis for scoping and prioritizing the work required and for comparing com-

[31] The material in Bordt (2017) provides a starting point for work on this issue.

[32] That differs from the kind of production where ecosystem services are combined with human inputs (labour, energy, etc.) to produce benefits.

pilation exercises across countries, including, for example, lists of ecosystem services attributed to grasslands.

5.25. The various ecosystem types are listed as the column headings of the proposed ecosystem services supply table in table 5.1, and the various ecosystem services are listed in the left column. The classification of ecosystem services follows CICES. The direct recording of the use of ecosystem services by type of economic unit appears in the ecosystem services use table, not in the supply table. However, it is important to compile information on the combination of ETs, ecosystem services and users at the same time.[33]

[33] The structures of FEGS-CS and NESCS explicitly incorporate this connection between supply and beneficiaries.

5.26. Examples of indicators that can be chosen to measure the flows of various ecosystem services are provided in section 5.6 along with relevant data sources.

5.27. The ecosystem services supply table shown in table 5.1 can be compiled in both physical and monetary terms. When the table is compiled in physical terms, each ecosystem service has a different measurement unit. In consequence, there cannot be an aggregation of ecosystem services because the relative importance of individual services cannot be immediately determined. However, aggregation within a single row to estimate a total supply from all ETs for an individual service is possible. Indeed, in practice, for some services, compilation may involve using aggregate information (e.g., country-level data) for an ecosystem service and then allocating that information to ETs and, potentially, to individual EAs.

5.28. Compilation in monetary terms is usually carried out by estimating values corresponding to the physical flows of each ecosystem service. Direct measurement of values may be possible for some provisioning services, however. The ecosystem services supply table provided in table 5.1 can then be extended, through the addition of rows, to record the total flows of ecosystem services in monetary terms. The estimation of values for ecosystem services is discussed in chapter VI.

5.2.6. Compiling the ecosystem services use table

5.29. The difference between the supply table and the use table stems from the fact that the use table focuses on the link between ecosystem services and different types of users, while the focus of the supply table is supply from ETs. Users include economic units classified by industry, government and household sector, following the conventions applied in the national accounts.

5.30. The need to have both supply and use tables arises because, while the supply of ecosystem services can be directly linked to a spatial area (e.g., an EA), there is no requirement that the user's location be the same as the location of the area from which the ecosystem service is supplied. Consequently, there is no straightforward connection between ET, ecosystem service and users that can be reflected in a single table. Different locations are the case especially for regulating services but also for some cultural services.

5.31. The link between users and the spatial areas from which ecosystem services are supplied is often complex, but its measurement is increasingly common (see Hein and others, 2016). In framing measurement in that context, it would be relevant to consider, for different ecosystem services, whether the beneficiaries are, in general terms, local, national or global. For example, in the case of most provisioning services, the users (e.g., farmers, foresters, fishermen, water supply companies) are located within the supplying EA, that is, at the point of extraction or use. That is also true of many cultural services with a recreational or touristic component. That is, although the beneficiary likely does not reside in the supplying EA, the ecosystem service is consumed when the user is present in the EA (e.g., walking in a forest, swimming in a lake). However, for many regulating services (e.g., air filtration), the users are located in neighbouring ecosystems or are global (e.g., with respect to carbon sequestration).

5.32. Given the lack of a straightforward connection between users and spatial areas, the choice of structure for the ecosystem services use table must be guided by possible uses and analyses of data. The structure of the use table in table 5.1 reflects the decision to display the allocation of the total supply of each ecosystem service to the various economic units, without distinguishing the precise location of the user. That provides a framing aligned to the structure of the data sets for the national accounts.

5.33. The ecosystem services use table, like the supply table, may be compiled in both physical and monetary terms. In physical terms, entries are limited to indicators for each ecosystem service. Since in accounting terms, supply must equal use, the unit of measurement applied for each ecosystem service must be the same in both the supply and use accounts in order for a balance to be obtained.

5.34. In monetary terms, entries for the total use of ecosystem services can be derived both for individual ecosystem service types and for total use by each user. The estimation of values for ecosystem services is discussed in chapter VI.

5.35. The presentation of the tables, as outlined here, may suggest that the estimates of the supply of ecosystem services would necessarily be compiled before measurement of their use, while in practice, the reverse may be the case. The preference should be for the compilation of the supply and use estimates to be carried out concurrently. For example, measures of provisioning services are likely to be estimated on a use basis, that is, on the basis of data on the extraction of materials (e.g., timber) from the environment by economic units. Indeed, since for all final ecosystem services, some link to economic units and other human activity must exist, there is a strong case to be made for compiling both the supply and use of ecosystem services at the same time.

5.3. Issues associated with the definition of ecosystem services

5.3.1. Introduction

5.36. Given the ambitious goal of integrating measures of ecosystem services with the standard national accounts, the measurement scope and definition of ecosystem services in SEEA EEA are established in relation to the production boundary of the SNA. The SNA boundary sets the scope for the measurement of GDP and related measures of production, income and consumption. In ecosystem accounting, the production boundary is expanded relative to the SNA, which reflects the fact that the supply of goods and services by ecosystems is considered additional production.

5.37. An important part of the rationale for measuring ecosystem services is that while much economic production (e.g., in agriculture, forestry and fisheries) utilizes inputs directly taken from ecosystems, those inputs and any associated costs of capital are not recorded in the standard accounting framework. According to the logic of SEEA EEA, in those situations, flows of ecosystem services should be clearly differentiated from the goods and services that are produced, that is, the ecosystem services represent the contribution of ecosystem assets to the production of those goods and services. In effect, that sets up an extended input-output or supply chain that includes ecosystem assets as suppliers.

5.38. It should be noted that the SNA production boundary currently includes goods and services produced through illegal activity and subsistence production, that is, these products form a part of the set of SNA benefits. The expansion in scope of the production boundary in SEEA EEA means that the ecosystem services providing input to the production of those goods and services is also recorded. Data and methods for measurement in those areas are discussed in *Measuring the Non-Observed Economy: A Handbook* (OECD, IMF, ILO and Interstate Statistical Committee of the Commonwealth of Independent States, 2002).

5.39. Another important component of the rationale for measuring ecosystem services is rooted in the understanding that there are many other, non-SNA benefits that are received from ecosystem assets by economic units and by society more generally. Hence, a full and proper accounting should incorporate the production of services by ecosystems, and the consumption of those services in economic and human activity.

5.40. Additional factors need to be taken into consideration so as to ensure that a clear measurement boundary is established, as discussed in section 5.3.2.

5.3.2. Distinguishing between ecosystem services and benefits

5.41. The SEEA EEA accounting model makes a clear-cut distinction between ecosystem services and the benefits to which they contribute. From an accounting perspective, that distinction is meaningful, because:

- It facilitates the description of the relationship between final ecosystem service flows and existing flows of products (SNA benefits) currently recorded in the SNA;
- It recognizes the role of human inputs in the production process and that the contribution of final ecosystem services to benefits may change over time (e.g., owing to changes in the methods of production);
- It helps to identify the appropriate target of valuation, since the final ecosystem services that contribute to marketed products (e.g., crops, timber, fish, tourism services) represents only a portion of the overall value of the corresponding benefits.

5.42. For those reasons, the goal of distinguishing between final ecosystem services and the corresponding benefits is appropriate for ecosystem accounting. It is also consistent with the approaches taken in TEEB (2010), Banzhaf and Boyd (2012) and the United Kingdom National Ecosystem Assessment (2011), although the precise boundaries, definitions and terms applied for this purpose vary in the different cases.

5.43. In practice, however, particularly at large scales, the articulation and application of this distinction can be challenging. The issues in this regard are different for provisioning services, regulating services and cultural services. The main challenge with respect to provisioning services is how to describe effectively the various ecosystem services involved in the supply of cultivated biological resources.[34] Those outputs, including crops, plantation timber and aquaculture, are considered benefits produced as a combination of final ecosystem services and human inputs. Since the balance of inputs between final ecosystem services and human inputs varies among production processes (e.g., hydroponic, irrigated and rain-fed agricultural production), using a measure of output from production as a measure of the quantity of ecosystem services is misleading.

5.44. For regulating services, there are generally no direct human inputs consumed in the production of benefits, although there may be economic activity associated with managing or altering an ecosystem to support the generation of such services (e.g., establishing vegetation as part of a carbon capture programme). However, it should be noted that the descriptions of the service and the benefits will be different: the description of the service reflects the action of the ecosystem asset (e.g., sequestering carbon

[34] "Cultivated biological resources" is a term defined in the SNA (para. 10.88) that supports the distinction between: (a) cultivated resources, that is, biological resources (timber, fish, animals, etc.) whose growth is considered the output of a process of production; and (b) natural biological resources, that is, resources whose growth is the result of natural processes.

or capturing air-borne pollutants), while the benefits should be described in terms of increased stability of climate and cleaner air. It is important that this distinction be made to ensure the correct focus for measurement and valuation. While changes in the volume of cleaner air, for example, may result from the presence of air filtration services or from reductions in vehicle emissions, only the former should be the focus of measurement for ecosystem accounting. It should also be noted that although there may be costs incurred in establishing or maintaining an ecosystem to support the supply of regulating services, those costs are not considered direct inputs to the generation of ecosystem services.

5.45. With regard to cultural services, the contribution of ecosystems is relatively passive: it is commonly the ecosystem that provides opportunities for people to, for example, engage in activities or have learning experiences. Costs may be incurred in enabling people to benefit from those services, for example, through construction of cycling or hiking paths, or visitor facilities. Often, cultural services are framed within the context of the benefits that people receive from engagement with ecosystems. The challenge for ecosystem accounting is to estimate the contribution of the ecosystem itself to the generation of benefits.

5.46. Meeting that challenge entails describing the ecosystem services appropriately so as to ensure in turn that the scope of measurement is appropriate. The focus should be on a description of those ecosystem processes that reflect what the ecosystem is doing to contribute to the production of the benefit. Overall, much further discussion on the framing and descriptions of ecosystem services and the corresponding benefits is required to ensure a common understanding of measurement in this area.

5.47. It should be noted that, in some cases, the physical measurement of ecosystem services presents larger challenges than those arising from measurement of services in monetary terms. For example, in the case of timber plantations, the SNA benefit is represented by the accumulation of wood in the plantation in a given time period, usually a year. The service comprises the various ecological processes that underpin the accumulation of wood, such as the storage of nitrogen and phosphorus and their release to the trees. As those services are difficult to quantify and aggregate in physical terms, in practice the accumulation of timber (measured in cubic metres) may need to be taken as the indicator for both the service and the benefit. In monetary terms, the benefit is represented by the value of the produced volume of timber. The service, on the other hand, can be valued using a residual approach (i.e., by calculating the resource rent) in order to specify the value of the contribution of natural capital involved in producing the benefit (see sect. 6.3 for further details).

5.3.3. Distinguishing between final and intermediate ecosystem services

5.48. All ecosystem services, both final and intermediate, should be considered in relation to ecosystem processes and ecosystem characteristics within ecosystem assets. A focus solely on final services reflects a recognition of the important role played by these processes and characteristics in directly supporting economic and human activity. The awareness that intermediate services may also be recorded in the accounting framework can foster a better conceptualization of the connections and dependencies among ecosystem assets. That attests to the potential of ecosystem accounting to facilitate: (a) a recognition of the contributions of all ecosystems and associated ecosystem processes wherever they are located; and (b) an understanding of the potential impacts of economic production and consumption on ecosystem assets.

5.49. While the use of accounting principles to distinguish between final and intermediate ecosystem services appears to be relatively straightforward, making that distinction in practice can be difficult owing to the complexity of the ecosystems themselves. At an aggregate level, a focus only on final ecosystem services may be sufficient, since many intermediate services represent flows between ecosystem assets within the same EAA. However, that may not be appropriate when considering the contribution of individual ecosystems or when undertaking accounting for smaller areas or individual ETs. In those cases, understanding the contribution of discrete EAs or ETs may be highly relevant, especially if an important function of an ecosystem asset is to support neighbouring ecosystem assets.

5.50. Such a case typically involves the intermediate services provided by upstream forests in regulating flows of river water and limiting the sediment content of water that is subsequently abstracted downstream, at which point, final ecosystem services would be recorded. In that case, it may be relevant to record the generation of ecosystem services by the forest ecosystem asset, the use of these services by the downstream water ecosystem asset (i.e., the river) and the generation of final ecosystem services by the water ecosystem asset at the point of abstraction.

5.51. Another case involves pollination. Pollination in croplands may depend upon pollinators that require shrub lands or a forest habitat, for instance, for shelter. If the shrub lands or forests were converted, the pollination service provided to those croplands would be diminished or lost. In that case, adding pollination services and biomass accumulation by crops would lead to double-counting. Thus, it is appropriate to map and record such intermediate services; otherwise, the services provided by different ecosystem types such as forests and shrub lands may be underestimated, e.g., in spatial planning.

5.52. The use of the term "intermediate services" in the *Technical Recommendations* may cause some confusion, which the following points are intended to help dispel:

(a) "Intermediate services" in this context corresponds to the term "intermediate consumption", as used in the SNA for flows of goods and services between producing economic units. In ecosystem accounting, intermediate services are supplied by one EA to another;

(b) In some circumstances, there may an interest in recording, as with flows within an economic unit, flows of services that are internal to an ecosystem asset. They can be recorded as required for analytical purposes. However, from a supply and use perspective, the net position would be zero for a single ecosystem asset;

(c) From an integrated economic-ecosystem perspective, final ecosystem services can be considered intermediate to the extent that they are inputs to SNA benefits, currently recorded goods and services. However, the term "final ecosystem services" is retained because it is commonly used and to convey that, from an ecosystem-only perspective, those services are final;

(d) In SEEA EEA, intermediate services are aligned with inter- and intra-ecosystem flows, that is, physical flows between and within ecosystem assets. Those physical flows (e.g., of water, nutrients, pollen) can be recorded and may be important in addressing certain analytical and policy needs. Information on those flows may also be of relevance in the estimation of intermediate services, but conceptually they are different from ecosystem services flows. By way of example, the retention of sediment by upstream forests is a service provided to downstream ecosystem assets, but the flow of the service is in fact characterized by the lack of a physical flow of sediment.

5.53. Notwithstanding the accounting possibilities with respect to intermediate services and that recording those flows may help in better understanding the flows of final ecosystem services and the contribution of different ETs, it is not advisable to attempt to measure all flows and dependencies between ecosystems in a systematic manner. Indeed, current ecological knowledge suggests that there are very significant measurement challenges. If information is required on intermediate services, the focus could be placed on measuring or modelling specific production functions (e.g., as related to pollination) or on using relevant contextual information. From an overall perspective, accounting for intermediate ecosystem services is an area for further research and testing.

5.54. The treatment of carbon sequestration and carbon storage demands special attention. In the ecosystem accounting approach, carbon sequestration is considered a final ecosystem service. As it is one of the principal means through which ecosystems mitigate climate change, the corresponding benefit is a reduction in the impacts of climate change. Carbon sequestration entails a flow of carbon from the atmosphere to the ecosystem, based on a variety of ecological processes. Within that context, it is important to distinguish between short-term flows (e.g., diurnal exchanges of CO_2 between vegetation and the atmosphere) and long-term sequestration, since it is only the latter that should be regarded as providing an ecosystem service.

5.55. Ecosystems may emit CO_2 as well as other gases such as methane and nitrous oxide. For example, carbon is emitted when peatlands are drained and forests cleared. While the emissions themselves are not ecosystem service flows, the loss of carbon from storage may be considered a reduction in the services provided by the associated ecosystem assets. However, further discussion is needed to determine the precise nature of any ecosystem services and possible approaches to their measurement and valuation.

5.3.4. Treatment of other environmental goods and services

5.56. As illustrated in figure 2.3 of SEEA EEA, not all flows from the biophysical environment to the economy and society can be considered ecosystem services. There are also a range of so-called abiotic services, for example, flows of mineral resources; flows of energy resources, including solar, wind, wave and geothermal energy; and, more generally, space for human habitation.

5.57. Since the focus of SEEA EEA is on accounting for ecosystems, the various flows are not incorporated in the ecosystem accounting model. On the other hand, many of those flows are considered in specific accounts presented in SEEA Central Framework (e.g., mineral and energy accounts, energy supply and use accounts, economy-wide material flow accounts and land-use accounts). At the same time, the fully spatial approach outlined in SEEA EEA suggests that, for the purpose of considering the full range of benefits derived from a defined area, it may be advantageous to incorporate measures of abiotic services in ecosystem accounts. However, the extension of the accounting tables in pursuit of that goal requires development.

5.3.5. Link between biodiversity and ecosystem services

5.58. The overall position taken by SEEA EEA is that biodiversity is a characteristic of ecosystem assets and is therefore of the greatest direct relevance to the measurement of their condition. According to the alternative view, biodiversity is a final ecosystem service supplied by ecosystem assets. Thus, measures of biodiversity, whether it is ecosystem-level or species-level diversity—the inclusion of genetic-level biodiversity measures has not yet been decided—are considered to be related primarily to the stocks component in the accounting model. That approach is consistent with the view that biodiversity can be degraded or enhanced over time, an attribute that applies only to stocks and not to flows (i.e., ecosystem services). There are some difficulties, however, associated with establishing the exact nature of the relationship between biodiversity and ecosystem condition, an issue that is discussed further in section 9.5.

5.59. At the same time, it is recognized that there are some elements of biodiversity, especially species-level diversity, that can supply final ecosystem services. Those include recreational services arising from wildlife-related activities, whereby people gain a benefit from experiencing the diversity of nature. In addition, people may appreciate, and therefore value, elements of biodiversity, for example, when they take an interest in the conservation of endemic or iconic species. In the latter case, specific elements of biodiversity (e.g., those related to the conservation of species) could be regarded as representing a "final use" of biodiversity. Given the potential links of biodiversity to both ecosystem assets and ecosystem services, it is relevant to recognize that measures related to biodiversity may be appropriate indicators in a variety of accounts.

5.60. Information on biodiversity, including on composition, state, functioning, and resilience, can be brought together in biodiversity accounts and ecosystem condition accounts and represented in such a way as to inform biodiversity management. The information in those accounts can include indicators reflecting the condition or state of the ecosystem, indicators reflecting the ability of biodiversity to support other services such as birdwatching, and indicators reflecting the appreciation of biodiversity itself through, for example, its provision of a habitat for endemic species.

5.3.6. Treatment of ecosystem disservices

5.61. Ecosystem disservices arise in cases in which the nature of the interaction between ecosystems and humans is considered "bad". Usually, that refers to the effects of entities emerging from ecosystems, such as pests and diseases, that exert a negative effect on economic production and human life. While SEEA EEA takes note of the issues associated with the measurement of ecosystem disservices, it does not offer a proposal on how to treat disservices in accounting terms.

5.62. Unfortunately, application of accounting principles does not facilitate efforts to record the outcomes associated with the production and consumption of products. Indeed, accounting, as distinct from economics, focuses not on the welfare effects of use but rather on the activity associated with the generation of products and the associated patterns of consumption. In consequence, all flows between producers and consumers are assigned positive values in the accounts, irrespective of their possible welfare effects. For example, the production and sale of cigarettes are recorded in the same way as the production and sale of apples.

5.63. A related issue is the treatment in ecosystem accounting of negative externalities, such as emissions and pollutants, which arise from economic and human activity, leading to declines in the condition of ecosystems. Any such environmental flows, such as emissions and pollutants, are not considered ecosystem disservices, and their negative impacts on welfare are not captured directly in accounting for ecosystem services. Instead, those negative impacts are captured in accounting for ecosystem condition. Hence, the effect of negative environmental externalities emerging over time, as attested by reduced flows of ecosystem services, all else remaining constant, should be captured by accounting for ecosystem condition.

5.64. Work is ongoing for both disservices and negative externalities on outlining their appropriate treatment within the context of the ecosystem accounting framework. It is to be noted that SEEA Central Framework provides accounting approaches to recording flows of emissions of greenhouse gases, pollutants and other residuals that can support measurement in those areas. Further, stocks and flows related to the measurement of externalities can be recorded in thematic accounts (see chap. IX), particularly the carbon account. The carbon account records flows (sequestration and emissions) and changes in stocks of carbon, which would include the recording of carbon emissions, for example, from drained peatlands.

5.3.7. Scope of cultural services within an accounting framework

5.65. Cultural services represent the area of ecosystem accounting where discussions and work on measurement are the least advanced. The challenges lie in articulating the distinction between ecosystem services and benefits, and in the associated realm of valuation. Where businesses are involved in the delivery of tourism and recreational services, treatment of measurement is quite clear-cut and parallels the measurement of provisioning services. However, the framing is less clear-cut in other cases, particularly in the case of so-called non-use interactions, wherein people obtain benefits from, but without any direct interaction with, nature. While it is highly plausible for ecosystem services related to non-use to be considered within the scope of ecosystem accounting, what is far less evident is whether the value of any non-use services would satisfy the valuation criteria required for ecosystem accounting, an issue that is discussed further in chapter VI.

5.4. Classification of ecosystem services

5.4.1. Introduction

5.66. The classification of ecosystem services is an important factor in measurement, since classifications can provide important guidance on how to ensure that measurement of the appropriate breadth and depth is undertaken or, at least, that individual measures are understood within a broader context. The discussion in the present section focuses on the use of an ecosystem services classification for accounting purposes. It is recognised, however, that such a classification will likely be utilized in other contexts as well, that is, it can serve multiple purposes.

5.67. The classification included in SEEA EEA was an interim version of CICES, which was updated to version 4.3 (see Haines-Young and Potschin, 2013). An update to Version 5.1 was released in 2017.

5.68. While CICES has been adopted for use in work on the MAES project (Maes and others, 2013), under the European Union Biodiversity Strategy to 2020, alternative approaches to the classification of ecosystem services have also been developed. Over time, it will be necessary to consider the respective merits of the different classifications and the roles that those classifications might play. Perhaps the most important alternative approaches are the classification system for final ecosystem goods and services (FEGS-CS), a product of the work of the United States Environmental Protection Agency (EPA) (see Landers and Nahlik, 2013), and the associated National Ecosystem Services Classification System (NESCS) (United States Environmental Protection Agency, 2015). The work of the United States Environmental Protection Agency has focused on the links between ecosystem types and the classification of the beneficiaries of the final services supplied by those ecosystem types. Work on the classification of ecosystem services is also under way within the context of Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, but progress from an accounting perspective has not yet been reviewed.

5.69. The CICES and NESCS classification systems can be seen as complementary. CICES focuses on defining services in accordance with a hierarchical structure based on types of ecosystem services, types of uses and types of flows. NESCS provides a systemic approach to classification, including nested hierarchical structures for types of ecosystems, types of ecological endpoints, types of uses and types of beneficiaries. FEGS-CS also entails a systemic approach, including types of ecosystems and types of use-beneficiary combinations.

5.70. One of the most important functions of a classification of ecosystem services is to frame discussions on the measurement and relative significance of ecosystem services. In effect, a classification can operate as a checklist for ETs and ecosystem services. Through its application in initial discussions, those ecosystem services considered most likely to be generated from a given ET would be grouped together. The resultant "baskets" of services for each ET can aid in discussions on the role of accounting, the structuring of information, the assessment of resources required for compilation and communication in general with regard to the breadth of the relationship between ecosystems and economic and human activity.

5.71. One finding derived from work on ecosystem services is that the choice of the words used to describe an ecosystem service can have a significant impact on how that service is perceived and understood by those involved. For regulating services in particular, the words used to articulate the human benefit received (e.g., reduced risk of a landslide) from the corresponding ecosystem service (e.g., soil retention) can be material to the selection of measurement approaches and to valuation. Further discussion across the full suite of ecosystem services, and on the related benefits, is required to ensure that measures and concepts are appropriately aligned.

5.72. There is a common misunderstanding that the role of classifications is to codify the distinction between final and intermediate ecosystem services. However, simply put, a specific type of ecosystem service cannot always be neatly categorized, neither as a service that contributes directly to economic units nor as a service that reflects the flows between ecosystem assets. In other words, it is not the type of the ecosystem service that determines whether it is final or intermediate but rather the user of the service, either an economic unit or an ecosystem asset, respectively. That being the case, for accounting purposes, work on classification must encompass both the description of ecosystem services and the capacity to distinguish among the users of those services.

5.73. Drawing up a complete listing of the different types of ecosystem services independent of the eventual users would be akin to establishing a classification of products supplied by economic units such as the Central Product Classification. A distinct classification of the ecosystem services received by specific types of users when those users are also known is akin to the Classification of Individual Consumption According to Purpose, which is used to classify only those products in the Central Product Classification that are the final consumption of households.

5.74. Those considerations on the role of classifications, and the potential connections to related economic classifications, are important for developing agreed accounting structures both in the case of ecosystem services alone and in the context of integrating measures of ecosystem services within standard accounting structures such as input-output and supply and use tables.

5.4.2. Proposed approach to the use of classifications

5.75. In the compilation of the ecosystem services supply and use account, an important step is to identify and define the services and the associated benefits supplied by the ecosystem assets within an ecosystem accounting area. CICES, FEGS-CS and NESCS can be used as checklists within that context. Further guidance is provided in table 5.2, which provides examples of services and benefits that may typically be supplied. The definitions of services and benefits in table 5.2 is broadly aligned with those found in the draft version of CICES 5.0 (an update to CICES 5.0 has been released). However, further discussion is necessary for the development of an ecosystem services classification system that is fully aligned with SEEA EEA while at the same time supporting application in other contexts. It is also to be noted that there may be a need to recognize differences at local and national levels based on experiences in the testing of ecosystem accounting.

5.76. It should be noted that in all of the examples set out in table 5.2, the service is defined as the ecosystem's contribution to the benefit. For example, in the case of timber, the ecosystem service pertains to the contribution made by the ecosystem to the volume of harvested timber, that is, the service is the accumulation of woody biomass in the ecosystem whose timber has been harvested. Accumulation of other biomass (e.g., in branches, below ground or in species that are not harvested) is not relevant for this service. In order for the physical output from the ecosystem to remain equal to the physical input into the economy, in the ecosystem services supply and use accounts, it is necessary for the volume of wood/timber that is recorded to be the same for both the service and the benefit, in those cases where it is appropriate to use volume of harvested timber as an indicator for both the service and the benefit. Felling residues are included in the service and in the benefit. The felled timber enters the economy inclusive of felling residues, but the residues return immediately to the environment. Those flows are referred to as natural resource residuals.

5.77. For timber harvesting, there is a difference in the time of the recording of the ecosystem services, depending on whether tree growth occurs in an ecosystem that is considered cultivated or in one considered natural. A timber stand in a plantation is an example of a cultivated biological resource, while a timber stand in a natural forest constitutes a natural resource. In reality, distinguishing between cultivated and natural resources includes a grey area. There are many ecosystems where management levels are intermediate in character (as, e.g., in the well-known case of jungle rubber forests, where enrichment planting increases the density of rubber trees). The distinction is based, inter alia, on ownership and, in particular, the degree of owner control over the ecological processes involved (e.g., planting of seedlings, pruning, fertilizing). SEEA Central Framework (sect. 5.25) presents guidance on how to distinguish between the two levels of management for national accounting purposes.

Table 5.2
Examples of ecosystem services and associated benefits

Service (contribution of the ecosystem to the benefit)	Benefit	Difference between services and benefits/final or intermediate
Provisioning services		**All provisioning services are final ecosystem services**
Timber: the accumulation in the ecosystem of timber to be harvested. For natural ecosystems, this is measured as the volume of wood extracted from the forest at the point of time of harvest (i.e., felled biomass), and for cultivated ecosystems (i.e., plantations), this is measured as the annual increment in harvestable timber	Timber: the volume of wood that is harvested. For natural ecosystems, this is measured as the volume of wood that is harvested (i.e., felled biomass), and for cultivated ecosystems (e.g., plantations), this is measured as the annual increment in the amount of harvestable timber	The service and the benefit are equal in physical terms but not in monetary terms; hence, making the distinction between services and benefits is fundamental for valuation. In monetary terms, the service can be measured on the basis of the resource rent generated by the ecosystem, i.e., on the basis of the revenue generated by the benefit minus the costs of production and harvesting including labour costs, user costs of fixed capital and costs of intermediate inputs. The benefit can be analysed in terms of revenue generated or value added, gross or net
Crop production: the contribution of the ecosystem to biomass accumulation by crops, i.e., the combined result of processes taking place in cropland that support crop production, such as infiltration of water, water-holding capacity of the soil, absorption of plant nutrients by soil particles and resupply of these particles to plants	Amount (e.g., tons) of harvested crops	In physical terms, there is no difference between the indicator for service (biomass accumulated) and the indicator for benefit (crops harvested). In monetary terms, the service can be valued on the basis of the generated resource rent, and the benefit, on the basis of the revenue generated or value added, gross or net
Water (e.g., used to produce drinking water): the amount (e.g., m^3) of water extracted from the ecosystem	The amount (e.g., m^3) of water extracted from the ecosystem, to be used, for example, for drinking-water production or for irrigation	When water is used for irrigation and supplied by a different EA than the EA where the crop is grown, the supply of irrigation water constitutes an intermediate service. Double counting needs to be avoided and the value of the irrigation water should be attributed to the EA supplying the water
Grazed biomass: the amount (e.g., dry weight) of grasses, herbs and other biomass grazed by domestic animals in cultivated or more natural ecosystems (e.g., pastures, savannahs)	Growth in livestock and the associated production of animal products (e.g., milk, wool). Domestic animals are "in the economy", and the service is provided at the time of the interaction between ecosystem and economy, for example, when biomass is grazed	

Table 5.2 (continued)

Service (contribution of the ecosystem to the benefit)	Benefit	Difference between services and benefits; final or intermediate
High water flow regulation (e.g., by mangroves, riparian vegetation, coral reefs)	Reduction in risk of floods and related events	Can be both final and intermediate
Water purification	Cleaner water	Can be both final and intermediate
Air filtration	Cleaner air	Can be both final and intermediate
Erosion and sedimentation control	Reduced sediment loads in water, reduced sediment deposition in downstream water basins	Can be both final and intermediate
Cultural services		All cultural services are final
Enabling/providing opportunities for nature-based tourism	Ecotourism (involving overnight stays)	Enabling/providing opportunities for nature-based tourism
Enabling nature-based recreation	Nature-based recreation (not involving overnight stays)	Enabling nature-based recreation
Enabling nature-based education and learning	Nature-based education and learning	Enabling nature-based education and learning
Enabling nature-based religious and spiritual experiences	Nature-based religious and spiritual experiences	Enabling nature-based religious and spiritual experiences
Enabling nature-based artistic and other human activities	Nature-based artistic and other human activities	Enabling nature-based artistic and other human activities

5.78. In the case of both cultivated and natural timber resources, the ecosystem service is defined as the accumulation of woody biomass used for timber harvesting. However, in the case of cultivated resources, the accumulation is recorded progressively on an annual basis, with the expectation that the total accumulated biomass will be harvested (unless natural disasters such as fires occur, which can be reflected in the timber stock recorded under "other changes in volume"). In the case of natural biological resources, the accumulation is recorded in total at the time of actual harvest of the forest timber.

5.79. This difference in recording can be explained as follows: in the case of cultivated resources, it is expected that all of the accumulated biomass will be harvested at the end of the growth cycle. In the case of natural forest resources, it is only the species of commercial interest that are harvested (as determined by age and quality of the individual trees, etc.); hence, the parts of the annual accumulation of biomass that will be harvested cannot be determined a priori in the case of natural resources. It should be noted that the distinction between cultivated and natural biological resources facilitates integration with the SNA, in which the same distinction between the times of recording is made.

5.80. For annual crops, the distinction between cultivated and natural biological resources effectively disappears. The large majority of crops are grown as cultivated resources, and since they are harvested on an annual basis, the annual accumulation of crop biomass equals the annual harvest, except in the case of natural disasters. In the case of annual crops, it is proposed that the annual harvest be recorded as a proxy for the ecosystem service provided. Also, in that case, the service equals the benefit, in physical terms.

5.81. In the case of provisioning services, in physical terms, the service generally equals the benefit. Conceptually, the service is the contribution of the ecosystem to the benefit. In the case of services arising from ecosystems that are to a high degree natural, it is clear that the ecosystem's contribution facilitates growth of the species that is harvested, be it wild strawberries, medicinal bark or an ocean-living fish. Since not all individual animals or plants that grow in the ecosystem are harvested, it is meaningful to record only the harvested animals and plants in the ecosystem services supply and use account. Consequently, in the case of natural and semi-natural ecosystems, the service equals the benefit in physical terms, for example, cubic metres (for timber) or kilograms (for fish).

5.82. In the case of services arising from cultivated ecosystems, such as a plantation, SEEA EEA, in line with the SNA and SEEA Central Framework, records the annual increment in biomass. The assumption in that case is that all biomass grown in a cultivated ecosystem, for example an acacia plantation or aquaculture system, is harvested (excluding losses due to natural disasters, etc.). In reality, those systems are often managed intensively by people. The contribution of terrestrial ecosystems is a function of the soil and its water- and nutrient-holding capacity, temperature, rainfall, etc. However, since all of these characteristics cannot be measured by one aggregated indicator, SEEA EEA assumes that in all cultivated ecosystems as well, service equals benefit, in physical terms. Hence, in all cases, for provisioning services, although not for regulating and cultural services, it is assumed, for measurement purposes, that service equals benefits, in physical terms—but not in monetary terms, as explained in chapter VI.

5.5. Role and use of biophysical modelling

5.5.1. Introduction

5.83. Biophysical modelling, within the context of the guidance provided by the *Technical Recommendations*, is defined as the modelling of biological and/or physical processes to achieve an understanding of the biophysical elements that are to be recorded in an ecosystem account. Those elements are associated either with ecosystem asset measurement, including ecosystem condition and ecosystem capacity to generate services, or with ecosystem services measurement. The focus of the present chapter is ecosystem services.

5.84. The intention of the present section is to provide general guidance on the types of biophysical modelling approaches that can be used to analyse ecosystem service flows, as distinct from modelling approaches that are applied to achieve an understanding of ecosystem processes (e.g., nutrient cycling, energy flows). A wide range of modelling approaches for the fields of ecology, geography and hydrology have been described in the scientific literature, many of which are of potential relevance to ecosystem accounting. Realizing that potential depends on such factors as the characteristics of the environment, the uses of the ecosystem, the scale of the analysis, and the available data. As it is impossible to describe all of these modelling approaches in a single publication, the present section focuses on providing an overview of the approaches and their main uses in the biophysical modelling of ecosystem services.

5.85. When applying biophysical models in ecosystem accounting, it is important to recognize the nature of the connections between ecosystem service flows and the condition of the relevant ecosystem asset. That connection is reflected in the concept of ecosystem capacity. Although the definition of ecosystem capacity remains a topic of ongoing discussion (see sect. 7.3), it is broadly accepted that the modelling of ecosystem service flows must take into consideration the current and expected future condition of the ecosystem and its various functions and processes.

5.5.2. Overview of biophysical modelling approaches

5.86. Ecosystem accounting generally involves a combination of spatial and spatial-temporal modelling approaches. Spatial modelling, which is required to produce maps of ecosystem services for a complete ecosystem accounting area, is most commonly undertaken using GIS packages such as ArcGIS and Quantum GIS.

5.87. There are also several ecosystem services-specific modelling tools such as ARtificial Intelligence for Ecosystem Services (ARIES), the Multiscale Integrated Model of Ecosystem Services (MIMES), the Land Utilisation and Capability Indicator (LUCI) and Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) (e.g., Bagstad and others (2013) for an overview and comparison of modelling tools). Several assessments of the relative strengths of those modelling tools have been published. In general, the tools differ in terms of sophistication, ease of use, capacity to handle large volumes of data and alignment with SEEA EEA framework.

5.88. Within the general GIS packages, spatial modelling tools that can be used to produce ecosystem services maps include lookup tables and interpolation techniques such as inverse distance weighting and kriging. In addition, specific GIS extensions such as maximum entropy modelling (MaxEnt) (see Philips, Anderson and Schepire, 2006) can be used. Lookup tables attribute specific values (e.g., for the amount of service supplied per hectare) to each EA. Inverse distance weighting algorithms are deterministic and predict values of unsampled points based on measured values of nearby points. Kriging and MaxEnt use statistical algorithms to predict the value of un-sampled pixels: kriging considers distance to sampled points as well as statistical relationships between sampled points in the interpolation; and MaxEnt predicts values for un-sampled pixels on the basis of the pixels' characteristics. MaxEnt has traditionally been used to predict the occurrence of specific species based on characteristics such as ecosystem type, ecosystem condition and distance to human settlements and roads. A critical requirement in applying geostatistical tools is that a sufficiently large sample size be available and that samples be representative of the overall spatial variability found. Examples of the applications of these approaches can be found, for example, in studies on rangeland ecosystem condition (Karl, 2010) and ecosystem services (Remme, Schröter and Hein, 2014).

5.89. In ecosystem accounting, modelling is required to estimate the potential and capacity of an ecosystem to generate ecosystem services. The dynamic systems modelling approach, which is based upon the modelling of a set of state (level) and flow (rate) variables and can be applied in combination with spatial models, facilitates an understanding of the flows of ecosystem services over time, including relevant inputs, throughputs and outputs. Dynamic systems models use a set of equations linking ecosystem condition or state, ecosystem management practices and flows of ecosystem services. For instance, a model may include the amount of standing biomass (state), regeneration of wood (flow), the harvest of wood (flow) and the price of wood (time-dependent variable).

5.90. A systems approach may include non-linear dynamic processes, feedback mechanisms and control strategies through which to handle complex ecosystem dynamics. However, understanding those dynamics and their spatial variability is often a challenge. Further, data shortages may be a concern for ecosystem accounting, which requires large-scale analysis of ecosystem dynamics and flows of ecosystem services. In addition, modelling a broad range of ecosystems services at fine resolutions and within large areas may entail prohibitive operating costs and data requirements. One possible way forward is guided by selectivity in applying temporal models (e.g., modelling efforts could be limited to services that show downward trends or constant flows over time could be assumed, at least initially, for services for which such trends are not apparent).

5.91. Erosion-control services resulting from vegetation cover are often modelled with the Universal Soil Loss Equation (USLE), although its reliability has proved to be variable in environmental contexts other than the ones for which it was developed (United States). Hydrologic process-based models include the Soil and Water Assessment Tool (SWAT) and the Sediment River Network (SedNet), model developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia). Those models, which are both temporally and spatially explicit, apply a modelling approach that is integrated within a GIS environment.

5.92. If data for specific ecosystem service flows are not available, new data collection and generation, including from inventories, remote sensing, spatial modelling and other sources, may be required. Data collection should be developed in such a way as to provide estimates across the different service types that are consistent (i.e., comparable as regards level of detail, quality, errors and uncertainties), as well as correctly reflect the ecological and land-use processes. Alternative modelling tools include:

- For soil and water-related processes and services: SWAT and SedNet, among others;
- For carbon-related processes and services: Carnegie-Ames-Stanford Approach (Potter and others, 1993); Moderate Resolution Imaging

Spectroradiometer (MODIS, MOD 17) algorithm (Running and others, 2004); BioGeochemical Cycles (Biome-BGC) model (Turner and others, 2011); and Organizing Carbon and Hydrology in Dynamic Ecosystems (ORCHIDEE) land surface model (Ciais and others, 2010), among others;

- For biodiversity and other services, where extrapolations of point (presence) data are relevant: MaxEnt among others, as described in chapter IX.

5.6. Data sources, materials and methods for measuring ecosystem services flows

5.6.1. Introduction

5.93. The stylized figures contained in SEEA EEA, chapter III, annex A3, depict the measurements required to estimate flows of ecosystem services. While those figures focus only on selected services, the logical basis of the models presented can be applied more generally. Recognition of the distinction between the ecosystem service and the associated benefit is of particular importance.

5.94. Generally, it is helpful for measurement purposes to distinguish among provisioning, regulating and cultural services. A classification of ecosystem services can serve as a useful checklist in that regard. Consideration of the measurement of ecosystem services in relation to ecosystem types, such as forests, wetlands and agricultural areas, is likely to be useful as well.

5.95. A useful tabulation of indicators for measuring ecosystem services is presented in the second European Commission report, chapter 5, on mapping and assessment of ecosystems and their services (Maes and others, 2014). Indicators for different ecosystem services are mapped across four broad ecosystem types: forest, cropland and grassland, freshwater, and marine. A review of this material highlights the broad range of data sources that will likely need to be considered for a full coverage of ecosystem services to be generated.

5.6.2. Data sources

5.96. Data sources are different in each country. It is suggested that important national data holders, who would be able to advise on data availability and quality, be involved in the process of compiling the accounts. Some relevant types of government departments and the kind of data they may maintain are as follows:

- National statistical offices: data on agricultural production (crops and livestock), health statistics (incidence of environmentally related diseases), population data, tourism data;
- Meteorological agencies: data on rainfall, temperature, climate variables;
- Departments of natural resources: data on timber stock and harvest, biomass harvest for energy, water supply and consumption, land cover (for estimating carbon stock and sequestration); remote sensing data (for estimating primary production); natural disaster statistics (on floods, landslides, storms);
- Water management and related agencies: data on water stocks and flows, abstraction rates; data derived from hydrologic modelling;

- Departments of agriculture: data on crop production, use of inputs in agriculture, erosion potential, biomass harvest;
- Departments of forestry: data on forest stock and harvest, growth rates of forests, carbon sequestration;
- Departments of environment and parks: data on iconic species habitats, visitors to natural areas, biodiversity.

5.97. Where national data are lacking, global data may be used. For example, there are now several global databases on soils such as the Harmonized World Soil Database and the ISRIC-WISE 3.1 soil profile database, as well as global data on soil properties derived from those databases (e.g., Stoorvogel and others, 2016). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM), developed by the Ministry of Economy, Trade and Industry of Japan and the United States National Aeronautics and Space Administration (NASA), can be downloaded from the GISAT website;[35] and several global data sets on forest cover are available from, for example, Global Forest Watch. MODIS provides satellite-derived global information on a range of land-, vegetation- and water-related indicators at a grid size ranging from 250 to 1,000 metres, often multiple times per year;[36] and WaterWorld provides global information on various hydrologic properties, including rainfall and potential evapotranspiration, at a resolution ranging from one hectare to one square kilometre.[37] However, as the level of accuracy of those products may typically be lower than that of national data sets, care should be exercised in applying those products for national-scale analyses, which should include, where feasible, validation of the data sets.

5.98. Studies conducted by local academic and government researchers on specific regions of a country or on specific services, as well as studies conducted on specific locations or services by international organizations (e.g., the United Nations Environment Programme (UNEP), the Convention on Biological Diversity secretariat and the World Bank), should also be reviewed and considered for integration into the ecosystem services supply and use account.

5.99. Databases in which research findings on valuation of ecosystem are stored (e.g., estimates of the monetary value of a lake's fish harvest) could also include information on the physical characteristics of the ecosystems valued (i.e., estimates of the fish yields in physical units).

5.100. The Environmental Valuation Reference Inventory (EVRI)[38] and the Ecosystem Service Valuation Database (ESVD),[39] which emerged from the TEEB (2010a) study, are two broad-based ecosystem valuation databases that can be investigated for country- or region-specific biophysical data. Other service- or region-specific databases or projects should also be investigated. On the other hand, whether the monetary valuations available from those databases are in fact appropriate for accounting purposes very much depends on the valuation concept applied (see the discussion on this issue in chap. VI).

5.101. In some cases, data may be available, for example, from an agricultural census, at a fine level of spatial detail. In other cases, it may be necessary, if subnational accounts are to be compiled, to allocate national- or regional-level estimates to the areas that are being used for ecosystem accounting by applying spatial modelling techniques.

5.102. Depending on the resources (including time) that are available, it may be feasible to collect new data. New data-collection activities could include:

[35] See www.gisat.cz/content/en/products/digital-elevation-model/aster-gdem.

[36] See https://modis.gsfc.nasa.gov.

[37] See www.policysupport.org/waterworld.

[38] See www.evri.ca.

[39] See www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database.

- Ecological field studies for determining a location-specific supply of ecosystem services. Such studies could, for example, collect data on water purification services of wetlands;
- Socioeconomic surveys conducted to facilitate a better understanding of how people and businesses use and value ecosystem services (as reflected, e.g., by water withdrawals, visits to recreational sites);
- Case studies of target populations (e.g., households near forest areas) conducted to facilitate a better understanding of their use of ecosystem services (e.g., biomass collected for fuel, forest products gathered for food, water extracted for household use).

5.103. The increasing amount of information available from multiple sources for ecosystem accounting purposes on measurement of ecosystem service flows, including examples, is likely to present the challenge of adapting, integrating and scaling that information. It is sufficient to note here that, from a practical perspective, the aim must be to measure the supply of ecosystem services for multiple ecosystem assets and types, and over a series of accounting periods. Adjustments should be made, as appropriate, to ensure that measures of different ecosystem services are related to common spatial areas and the same time periods. The issue of scaling is considered in section 5.6.3.

5.6.3. Measuring ecosystem services supply

5.104. The measurement of provisioning services can generally be linked to measures commonly available in statistical systems. Data on crops, and other agricultural products, livestock, and forestry and fisheries products are all relevant to the estimation of provisioning services.

5.105. For measurement of some cultural services, particularly those related to tourism and recreation, the use of available administrative and survey-based information is appropriate. The measurement of non-use cultural services is more challenging.

5.106. Some specific suggestions for measurement of regulating services using biophysical models, as adapted from Hein, 2014, are provided in table 5.3. Those suggestions, however, are intended only as a starting point for research and testing.

5.107. In measuring the supply of all types of ecosystem services, it is important to also consider the use of ecosystem services and the type of user. That subject is discussed in subsection 5.6.4.

Table 5.3
Possible ecosystem services metrics and mapping methods for selected regulating services

Ecosystem service	Potential metric	Description
Climate regulation and carbon sequestration	Tons of carbon (or carbon dioxide) sequestered per year, per hectare or per square kilometre	There are two basic approaches to analysing carbon sequestration in ecosystems. The first is to compare changes in stocks of carbon over time, for instance, on the basis of forest inventories; below- and above-ground carbon stocks in various forms need to be included in such assessments. The second is to estimate flows of carbon, although this method can yield results of considerable uncertainty; in this case, carbon sequestration can be related to net ecosystem productivity, i.e., the difference between net primary productivity and soil respiration. Carbon sequestration rates in specific ecosystem types can be derived from the literature and from Intergovernmental Panel on Climate Change-based greenhouse gas inventory estimates for land use, land-use change and forestry, and used to produce lookup tables. Net primary productivity can also be derived from the normalized difference vegetation index, which can be calculated through use of remote-sensing images. However, in this case, care needs to be taken that the relationship between the normalized difference vegetation index and net primary productivity is well established for the ecosystems involved, and that accuracy levels are calculated based on sample points. Net primary productivity can be combined with estimates of soil respiration to estimate carbon sequestration using pixels. However, it is often difficult to find credible values for the spatially very variable soil respiration rate, which depends on activity of bacteria and fungi. This activity is in turn guided by the local availability of organic matter (e.g., fallen leaves), temperature, moisture, etc.
Maintaining rainfall patterns	Millimetres of water evapo-transpiration (hectare/year); millimetres of rainfall generated (hectare/year)	Rainfall patterns depend on vegetation patterns at large scales. For instance, it has been estimated that maintaining rainfall patterns in the Amazon at current levels requires maintaining at least some 30 per cent of the forest cover in the basin. Reductions in rainfall in the western Sahel and the Murray-Darling basin in Australia have also been correlated to past losses of forest cover. Maintaining rainfall patterns is a significant ecosystem service that it is difficult to estimate at the level of individual pixels, since this service requires an understanding of large-scale, complex climatological patterns, large-scale analyses of potential damage costs, and interpolations, with detailed climate-biosphere models, of values generated at large scales to individual pixels within those areas.
Water regulation	Water storage capacity in the ecosystem in cubic metres/hectare or in millimetres; Difference between rainfall and evapo-transpiration in cubic metres/hectare/year	Water regulation entails several different activities, including: (a) flood control; (b) maintaining dry-season flows; and (c) water-quality control (e.g., by trapping sediments and reducing siltation rates). Temporal—that is, inter-and intra-annual—variation is an especially important consideration for the water regulation service. Modelling this service, which is often data-intensive and analytically complex, generally requires the use of hydrologic models. Obtaining the stream flow and other data needed to calibrate the models and, at aggregated scales, securing sufficient computing power constitute particular challenges
Storm and high-water protection	Surface-water modelling can be deployed for analysis of reduction in flood risk, expressed, depending on context, as reduction in: (a) probability of occurrence; (b) average flood duration; or (c) water level	Storm and high-water protection commonly depends on linear elements in the landscape that act as a buffer against high water levels (e.g., a mangrove, dune or riparian system). Modelling this service requires the modelling of flood patterns and the influence of vegetation, soil types and topography. It is also necessary to define the benchmark against which the reduction in risk can be assessed It may not always be necessary to model flood protection in physical terms in order to achieve an understanding of the monetary value of the service, in particular in those areas where it is certain that natural systems, if lost, will be replaced by artificial ones (e.g., a dyke), as in most parts of the Netherlands, for instance. In this case, valuation may be carried out on the basis of a replacement cost approach, which does not require an understanding of the physical service in full

Table 5.3 (continued)

Ecosystem service	Potential metric	Description
Erosion and sedimentation control	The difference between sediment run-off and sediment deposition in tons/hectares/year; and current ecosystem state compared with a situation with no plant cover	There is a relatively extensive amount of experience in modelling this service. Erosion models can be integrated into catchment hydrologic models—such as the Soil and Water Assessment Tool (SWAT) and SedNet (developed by CSIRO), which are both freeware—to predict sediment rates. In SWAT, a watershed is divided into hydrologic response units, which possess homogeneous land-use, management and soil characteristics. Erosion rates must be estimated for each hydrologic response unit, for instance, on the basis of the modified universal soil loss equation (MUSLE) or revised universal soil loss equation (RUSLE) erosion models. Alternatively, the SWAT landscape model, which includes grid-based land cover units, can be used.
Water purification	Amount of excess nitrogen and/or phosphorus captured in the ecosystem	Various hydrologic models, including SWAT, contain modules that enable estimation of the nutrient loads in rivers as a function of stream flow, discharge, temperature, etc. Nitrogen is broken down by bacterial activity, and phosphorus is typically removed from ecosystems by binding to soil particles. Modelling these processes requires large data sets, preferably with daily time steps, for nutrient concentrations in various sampling stations along the river course

Source: Adapted from Hein (2014).

5.6.4. Recording ecosystem services users

5.108. Within the ecosystem accounting model, all ecosystem services must have a corresponding user. Users—including those resident in a given country and those resident in the rest of the world—are economic units that can be grouped, according to broad national accounting categories, as corporations/businesses, governments or households.

5.109. Other groupings of economic units that might be considered include:

- Industry-related groupings, whereby individual establishments or businesses that undertake similar activities such as agriculture or manufacturing are classified together;
- Groupings based on allocations of use of ecosystem services, by household income levels;
- Groupings based on rural/urban use of ecosystem services;
- Groupings based on whether services are used locally, nationally or globally.

5.110. To the extent that these various groupings of users can be identified during the data-collection stages, there is a potential for developing information sets that are relevant to a broader range of policy questions.

5.111. When measuring the supply of ecosystem services and mapping it across ecosystem types (e.g., forests), consideration of the link to users is likely to be helpful. This approach has been applied extensively in the development of FEGS-CS and NESCS by the United States Environmental Protection Agency (see Landers and Nahlik, 2013; and United States Environmental Protection Agency, 2015).

5.112. In support of the integration of the measurement of the supply of ecosystem services with the national accounts and associated tables, such as input-output tables, it is recommended that with regard to the matching of ecosystem services to users, the classification of users applied in the national accounts either by institutional sector or by industry/economic activity, be utilized.

5.7. Recommendations for measuring ecosystem services

5.113. Whether minimum, partial or fully spatial, a practical approach to developing ecosystem service supply and use accounts is in many cases gradual, starting with the inclusion of a selection of ecosystem services. It is likely to be a step-by-step approach focusing initially on a limited set of ecosystem services that can over time be expanded into a more comprehensive set of services. Generally, the selection of the initial set of services depends upon policy priorities, data availability and the computational complexity of the analysis of the service.

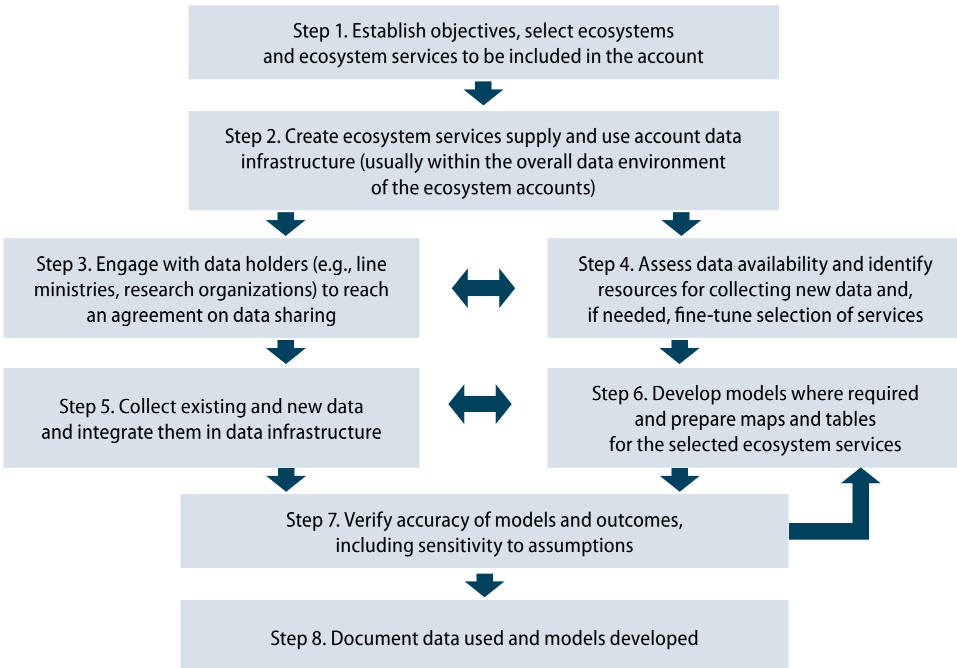
5.114. Figure 5.1, in the form of a flow chart, provides a generalized illustration of the steps involved in measuring ecosystem services for compilation of the ecosystem services supply and use account. It is crucial that ecosystem accounting be undertaken with the understanding that it is not meant to be a one-off exercise. During the period of time needed for development of ecosystem services models, existing models can be refined, and new models can be developed. An integral component of steps 3 to 7 entails addressing the need to identify data and knowledge gaps, to propose improvements to monitoring systems, as well as related models and tools, and to work with data holders on enhancing the quantity and quality of the input data.

5.115. It is clear that many of the data needed to compile ecosystem services supply and use accounts need to be derived from models, including process models and models for interpolation and extrapolation of data. There are several obligations imposed, arising from the use of data from models, in particular complete transparency in the provision of information on the models and the particular details of the equations on which the models are based, the models' statistical significance, and the input data used and their quality. The integrity of the accounts is undermined if such information is not included along with those data. In addition, a clear and detailed description of the data and models used would be essential both in supporting the process through which accounts are being regularly updated and improved, and in managing possible staff changes in the national statistical offices and research organizations that underpin the production of the accounts.

5.116. The most appropriate initial suggestion for each country seeking to undertake pilot studies in ecosystem accounting is to utilize its likely already-existing large body of work as a basis for estimating flows of ecosystem services. On the other hand, it is unlikely that estimates of ecosystem services for specific ecosystems in each country will have been developed in a relatively standardized way. Consequently, it is the role of the ecosystem accountant to gather the available expertise and research. Advancement of the measurement of ecosystem services in the short term will thus be achieved through testing rather than through primary research.

5.117. It is valuable, once a set of priority services has been established, to quantify and map the ecosystem services in terms of both supply (from ecosystem units) and use (by, e.g., businesses, households and governments). Relevant data sources and modelling techniques have been described in sections 5.5 and 5.6.

Figure 5.1
Flow chart for developing an ecosystem services supply and use account



5.118. An example of a pilot analysis of ecosystem services for Central Kalimantan, Indonesia is provided in box 5.1.

5.119. It is recommended that the ecosystem accounting framework be used to build an understanding of the gaps in information, with respect to the overall coverage of various ecosystem services and the extent to which estimates include the supply of ecosystem services from all ecosystem types. The accounting framework can play an important role in identifying such data gaps and supporting a discussion of priorities for additional data collection. Depending on the nature of the data gaps, benefit transfer functions may be considered for use and may be cautiously tested.

5.120. The identification of data gaps may be carried out by establishing a list of priority ecosystem services based on existing national practices related to land and water management and nature conservation. For this task:

- FEGS-CS or NESCS, as developed by the United States Environmental Protection Agency, can be applied as an analytical tool, since both classification systems contain a broad set of "origin points" of services, linked to types of ecosystems and beneficiaries;
- CICES, FEGS-CS or NESCS can be used as a checklist.

5.121. Generally, when ecosystem services are being defined, classified, quantified and mapped, it is important to develop an understanding of uncertainties and to prepare validation and quality-control data and protocols.

5.8. Key research areas

5.122. While testing is to be the priority focus of current activity, it could at the same time draw support from specific areas of research. Of particular relevance are efforts being directed towards resolution of issues concerning the definition and classification of ecosystem services. Work in this regard has advanced significantly, including delineation of the relevant boundary issues. However, putting in place a classification of ecosystem services that is appropriate for accounting purposes requires further consultations.

Box 5.1

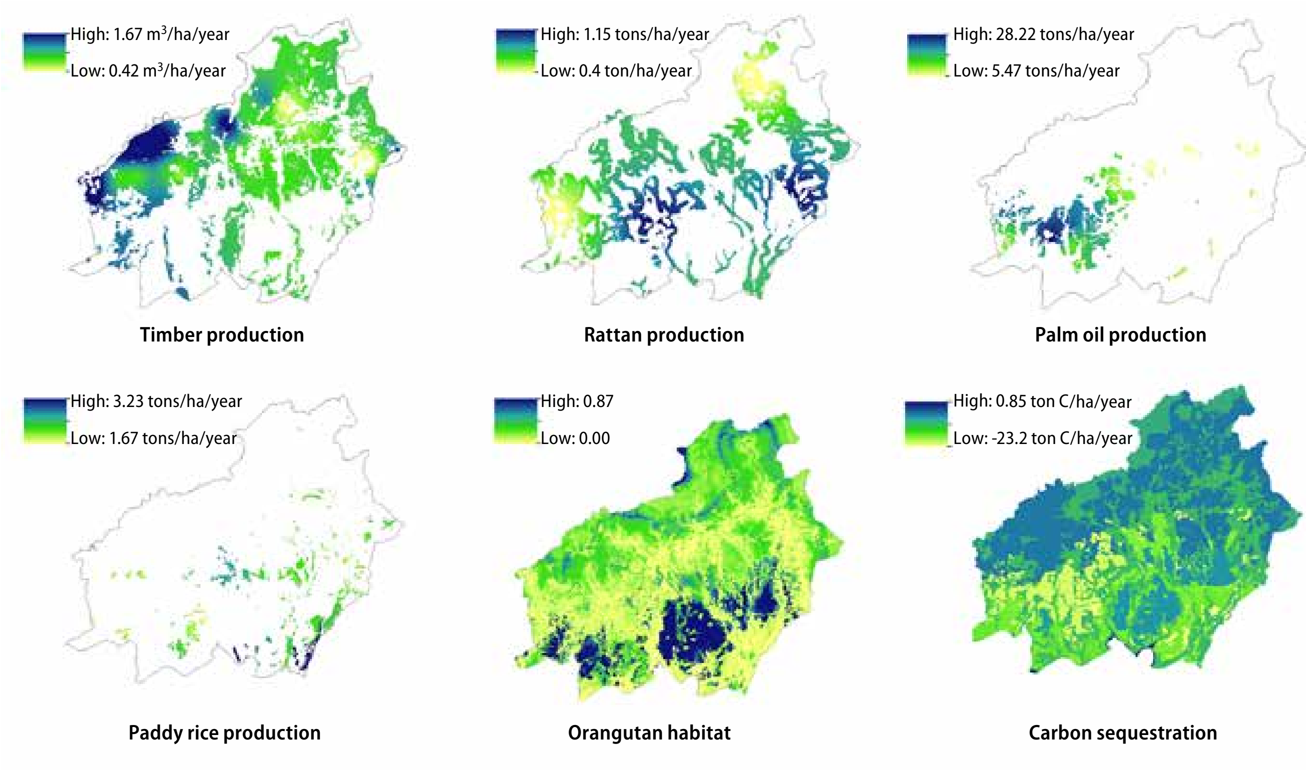
Ecosystem services mapping in Central Kalimantan, Indonesia

Under a 2014 project carried out at Wageningen University, Netherlands, seven ecosystem services were mapped, following SEEA EEA guidance, in Central Kalimantan Province, Indonesia, for the year 2010. Mapping the seven selected ecosystem services required a specific data set for each service. The data were collected from a variety of sources, including existing land cover maps, soil maps, digital elevation models, and topographic and hydrologic maps. The land cover, topographic and hydrologic maps are all available in vector format. All spatial input data were converted to raster format with a pixel size of 100 metres for further spatial analysis. Spatial data were combined with statistical data from Indonesia on rice, timber and palm oil production. Furthermore, survey data from various published studies were used to analyse rattan cultivation, tourism and rice production, and company data were used for timber production. The services were connected to a land-cover map from 2010; and ecosystem services data from 2010 were used as much as possible. However, for some services, data from 2009 or 2011 were used as a proxy. The map below specifies ecosystem services supply in Central Kalimantan in 2010.

In constructing the map, it was found that ecosystem services supply could not be related to a set of ecosystem properties, including soil, rainfall, slope, soil and vegetation biomass, with sufficient reliability (typically, R2 < 0.2 for all provisioning services). The explanation may be that there is no strong correlation between ecosystem properties and extraction rates of provisioning services, with extraction rates being an overriding factor in determining flows of provisioning services. As a result, various spatial modelling techniques were used to produce wall-to-wall mapping of ecosystem services. Those techniques included lookup tables, interpolation, regression modelling, and probabilistic models such as MaxEnt.

Provisioning services are commonly supplied in only one type of land-cover class; but within these land-cover classes, there can be substantial variation in supply. Provisioning services were therefore mapped using spatial interpolation rather than lookup tables. Use of the latter results in a specific value for a given land-use class. Interpolation was carried out using ArcGIS with ordinary kriging. Note that the habitat service is included as a service in the map, expressing both biodiversity and the potential to support tourism. This service was mapped with MaxEnt. For carbon, spatial interpolation was not pursued owing to an insufficient number of observations, although it is likely that spatial variation within ecosystem types also occurs. For carbon sequestration, a lookup table, specifying the amount of sequestration in each ecosystem type based on values found in the scientific literature was therefore used.

Ecosystem services supply in Central Kalimantan, Indonesia (2010)



Source: Sumarga and Hein (2014/2015); and Sumarga and others (2015).

5.123. The second key area of research is focused on articulation of the treatment and measurement of intermediate services in ecosystem accounting. A related task is specification of what are best referred to as ecological production functions or value chains, that is, the sequence of ecosystem processes, possibly across ecosystem types, that result in the supply of a final ecosystem service. Although it is not anticipated that a complete catalogue of such production functions will be established in the short- to medium-term, research along these lines would be of direct benefit in the application of ecosystem services and ecosystem accounting measures to policy questions. Examples of relevant ecological processes include growth (e.g., of timber), decomposition, soil erosion, habitat fragmentation, water run-off and yield.

Chapter VI
Valuation in ecosystem accounting

Key points

- The estimation of monetary values for ecosystem services and ecosystem assets can be undertaken for a variety of purposes. It is essential to ensure that the purposes of such valuation are well understood.
- In ecosystem accounting, the primary goal of valuation in monetary terms is the integration of information on ecosystem condition and ecosystem services with information in the standard national accounts. The purposes in that regard are to support: (a) comparison of ecosystem services with the production and consumption of other goods and services; and (b) the use of ecosystems-related information in standard economic modelling and productivity analysis.
- For those purposes to be achieved, the valuation concepts and approaches used for ecosystem accounting need to be consistent with the valuation concept used in the national accounts, that is, the concept of exchange values. Exchange values reflect the price at which ecosystem services and ecosystem assets would be exchanged between buyer and seller if a market existed.
- For other policy and analytical purposes, different valuation concepts will be appropriate, including for application to the estimation of welfare-based values and the use of non-monetary valuation techniques. Although those concepts should not be applied to derive monetary valuations for ecosystem accounting, the broader ecosystem accounting model illustrating the relationships among ecosystem assets, ecosystem condition and the ecosystem services supplied are still relevant. Wherever possible, a common data set on ecosystem stocks and flows in physical terms should be used to underpin valuation studies, irrespective of purpose and the valuation concept being applied.
- Recent investigation into the potential for using the range of non-market environmental valuation techniques suggests that many are relevant or may be adapted for use in accounting. Nonetheless, extensive further discussion and testing on the use of valuation methods for the estimation of exchange values are required.
- In ecosystem accounting, the valuation of ecosystem services is the starting point for the valuation of ecosystem assets. A clear distinction should therefore be made between these two objects of valuation.

6.1. Introduction

6.1. The issue of valuation can complicate the discussion of ecosystem and natural capital accounting for many reasons. From one perspective, valuation implies that an inappropriate and misleading "dollar value" is being placed on all environmental assets and services. Another contention is that the environment is far too complex a subject to lend itself to the compilation of useful measures in monetary terms. Further, there are differing views on monetary valuation in ecosystem accounting with regard to purposes, concepts and techniques.

6.2. The ambitious aim of the present chapter, like that of SEEA EEA, chapter V, is to provide a possible pathway for negotiating the various issues related to valuation in ecosystem accounting, so that discussions can be placed in a context encompassing other approaches and perspectives.

6.3. One general conclusion is that valuation in monetary terms requires careful consideration of the purpose of the valuation. Purposes include not only accounting but also the assessment of welfare under alternative scenarios, among others. Once the purpose is defined, the appropriate valuation concept can be selected, which will determine the relevant valuation method and technique to be applied. Often, however, the discussion on environmental valuation moves directly to the issue of method and technique without recognizing the different purposes of valuation or, in consequence, the valuation concepts that may be relevant.

6.4. It is clear that the major part of the work in the area of valuation has been motivated by an interest in assessing trade-offs between different potential land uses. Indeed, monetary valuation of ecosystem services has a particular relevance in the context of measuring differences in the economic surplus associated with different scenarios, following a standard cost-benefit type methodology. Other work has focused on the measurement of shadow prices for ecosystem assets, taking into account relevant externalities. To many of those within the ecosystem services valuation space whose work is undertaken from such an analytical perspective, the focus on exchange values of ecosystem services for accounting purposes may understandably appear inappropriate or irrelevant.

6.5. Ecosystem accounting is designed, however, to support a different analytical and policy purpose, which is, in particular, to encourage and support the use of environmental information in standard economic and financial decision-making. Within this context, the measurement of the value of ecosystem services in exchange values supports direct integration with standard financial and national economic accounting data. Thus, the data can be used directly to extend standard economic modelling approaches and to enhance broad indicators of economic performance such as national income, savings and productivity. While these measures and applications are different from the more common applications of ecosystem services valuations, the ability to view ecosystems through multiple analytical lenses is a strong motivational factor for continuing to develop valuations for accounting purposes.

6.6. A fundamental principle of valuation in an accounting context is that the first step should be the valuation of individual ecosystem services. In general, this will require application of an appropriate monetary value to an imputed exchange of (or transaction in) ecosystem services between a given ecosystem asset (e.g., a forest) and an economic unit (e.g., a forestry company) or individual (e.g., a visitor to a forest).

6.7. The task of valuing ecosystem assets has distinct characteristics. A comprehensive valuation requires an estimation of the future flows of ecosystem services that are expected to be supplied by an ecosystem asset. In some cases, for example, that of agricultural land, while observed market values for such land can be related to the value of ecosystem assets, prices will likely not only include non-ecosystem-related values (e.g., the potential of land for development) but also omit non-marketed ecosystem services (e.g., water regulation services). Thus, the valuation of ecosystem assets goes beyond that aforementioned first step of valuing individual ecosystem services.

6.8. This chapter outlines the main valuation principles for ecosystem accounting, which includes distilling the key insights presented in SEEA EEA, chapter V, while incorporating a range of considerations that have emerged since the issuance of that publication (sect. 6.2); examines relevant data and source materials (sect. 6.3); and discusses key challenges and research areas in valuation (sect. 6.4). The final section is a concise presentation of valuation-related recommendations based on current knowledge and practice and the key issues requiring further research. The recognition in chapter VII of the distinct nature of the task of valuing ecosystem assets is reflected in its examination of the issues related to the valuation not only of ecosystem assets but of ecosystem degradation as well.

6.2. Valuation principles for ecosystem accounting

6.2.1. Introduction

6.9. SEEA EEA recognizes that the meaning of the term "valuation" can vary depending on the context. For accountants and economists, valuation almost always signifies the placing of a monetary value on assets, goods or services. In other contexts, the term may denote a more generalized recognition of an entity's significance. While the focus in SEEA EEA is on valuation in monetary terms, the role or importance of other concepts of value should not be discounted. Indeed, accounting for ecosystem condition and ecosystem services in physical terms may provide a relevant information base for non-monetary valuation.[40]

6.10. Monetary valuation in SEEA EEA is applied to ecosystem services and assets, with the relevant valuation concept for ecosystem accounting being exchange value.[41] If there were observable markets in individual ecosystem services, an exchange value would reflect the prices paid by users of ecosystem services to the relevant producers (i.e., the relevant ecosystem assets). Since many transactions involving ecosystems are usually not reflected in observed monetary exchanges, exchange values must be estimated using non-market valuation techniques. There are some exceptions, including cases where payments (e.g., stumpage fees paid by the forestry industry) are made to owners of resources; depending on their nature, these payments may reflect values for associated ecosystem services.

6.11. Techniques developed for non-market environmental valuation are well established and broad-ranging. The extent of such development is reflected in key publications (e.g., Freeman, Herriges and Kling 2014; and Champ, Boyle and Brown, eds., 2017). From a national accounts perspective, the work on environmental valuation has been commonly characterized as inappropriate, because its techniques are often applied with a view to procuring answers to questions regarding changes in welfare associated with different environmental situations (the concept of welfare values is distinct from that of exchange values required for accounting purposes). Indeed, the adoption of this characterization by SEEA EEA is reflected in its alignment of environmental valuation with the estimation of welfare values.

6.12. With the progress in the discussions between environmental valuation experts and national accountants as evidenced in recent years, clear evidence has emerged of far more common ground than was previously identified. While this does not guarantee that the path ahead will be straightforward, there are nonetheless solid reasons for anticipating that the research and development conducted by economists in environmental valuation can be adapted for use in accounting contexts. Research aimed at understanding and documenting the features of that common ground, as well as remaining challenges, is currently under way in the context of the WAVES project. A paper examining the connections between these two perspectives on valuation has been prepared as part of the programme of research of the WAVES partnership (see Atkinson and Obst, 2017). This chapter highlights some of that paper's key findings, while at the same time recognizing that further investigation and discussion will be required.

40 A useful introduction to different concepts of valuation, including both monetary and non-monetary valuation, is provided by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (see Pascual and others, 2017; see, also, Maynard and Davidson, 2015).

41 The term *exchange values* is used in SEEA EEA, since the term *market prices* as commonly used in the SNA has been often misunderstood as signifying that national accounting incorporates only values of goods and services transacted in markets. An alternative term for the target valuation concept is *transaction prices*, which may be substituted for *exchange values* without loss of meaning.

6.2.2. Establishing markets for exchange values

6.13. As has been noted, underpinning the estimation of exchange values is the construction of a transaction or exchange, carried out in a market setting, between ecosystem assets and economic units, businesses, governments or households. Since the assets themselves are not actual market participants, the challenge in valuation for accounting lies in establishing the assumptions regarding the institutional arrangements that would apply if there were an actual market involving ecosystem assets.

6.14. One approach entails identifying parallels between existing market transactions and transactions in ecosystem services. A reasonably close connection can be established between some of those services and market activities. This generally holds for provisioning services contributing to the production of food, fibre, fuel and energy, which can be valued using observed values for the associated marketed products. In this case, a close connection can be made to the values used in the SNA to estimate production and consumption. The values of these types of ecosystem services may be described as "near market" (see Nordhaus, 2006; and Farley, 2008). The implicit assumption within this context is that the institutional arrangements underpinning the exchanges of ecosystem services are the same as those for closely associated products.

6.15. On the other hand, many ecosystem services contribute to benefits that are not closely connected to existing markets. Often, these are services that may be regarded as providing public goods, as in the case, e.g., of the contribution of ecosystems to flood protection. Determining valuation techniques for the estimation of exchange values in these situations is a more complicated task, since the nature of the appropriate institutional arrangements is not clear-cut.

6.16. In standard national accounting, the recording of values does not rely on the making of specific assumptions regarding institutional arrangements. That is to say, the national accounts record transactions and associated values as they are revealed in exchanges between economic units without adjustment for the nature of the underlying institutional arrangements. Thus, national accounting records observed exchange values in open and in regulated market situations equally.

6.17. While standard national accounting is structured to record observed exchanges in all market structures, this still leaves open the question of what institutional arrangements should be assumed in the case of ecosystem service valuation when there is no existing market. Generally, national accountants, being relatively pragmatic in such contexts, are likely to consider what market arrangements would be most likely, given the particular country, the likely behaviour of market participants, existing tax and regulatory settings, and the type of ecosystem service. Since accountants, who record past events, will carry out these types of assessments retrospectively, the estimation context is therefore somewhat different from that where such assumptions are being made with respect to future behaviour or alternative scenarios.

6.18. Key in this regard is to recognize that the aim of national accountants is to estimate the value that would have been revealed under the "most likely" institutional arrangements. A useful research topic for specialists in non-market valuation could therefore be the description of possible institutional arrangements and assumptions under most likely scenarios.

6.2.3. Estimation of changes in welfare and consumer surplus

6.19. A common application of non-market environmental valuation techniques is to the estimation of changes in welfare, including producer and consumer surplus associated with environmental externalities, both positive and negative. Since exchange values used for national accounting explicitly exclude consumer surplus, it has been assumed that the associated valuation techniques are inappropriate for national accounting purposes. In fact, in estimating changes in welfare, most valuation techniques proceed by delineating a demand curve, each of whose points represents an estimation of the combinations of price and quantity for a good or service that would satisfy a given set of consumers. Along this demand curve, there will be a point of intersection with a corresponding supply curve. The supply curve delineates the combinations of price and quantity at which a supplier is willing to provide the same good or service. The point of intersection represents an "exchange value". Through consideration of this connection between welfare-focused analysis and exchange values, a pathway opens up towards linking standard non-market environmental valuation techniques with the requirements of national accounting. These possible connections are further described in the following sections.

6.20. Establishing the connections between welfare values and accounting values will hinge on clarification of the assumptions regarding institutional arrangements. If national accountants are to engage effectively, they need to: (a) recognize that, from an economist's perspective, such arrangements are a key focus of work on non-market valuation; and (b) provide more clarity in this area. By way of example, Day (2013) observed that under the assumption that ecosystem assets are perfectly price-discriminating—that is, as suppliers, they charge exactly what each user is willing to pay—consumer surplus is eliminated and each of the estimated prices reflected in the demand curve will be an exchange value. If such an institutional arrangement was considered reasonable for accounting, this would have material impacts on valuation for accounting purposes. Day's observation also highlights the need to consider assumptions concerning user and consumer behaviour in relation to ecosystem services. In this case, while there may not be support for adopting this specific behavioural assumption, the general point holds. Overall, both economists and accountants need to consider demand and supply factors in estimating exchange values.

6.21. One concern regarding the use of exchange values, and hence the exclusion of consumer surplus, is that it is likely: (a) to generate relatively lower values for ecosystem assets that are more distant from economic units; and (b) to fail to incorporate potentially important non-use values. There are also cases where a relatively large share of the welfare generated by ecosystem services takes the form of consumer surplus. For instance, in the case of air filtration, an important part of the welfare generated is related to prevention of the sickness and premature mortality resulting from air pollution. In this case, the accounts would assign a lower value for this service —notwithstanding the potential to record significant direct economic effects through reduced health costs and productivity—, compared, for example, with the higher welfare value that takes into account additional life years (e.g., Remme and others, 2015).

6.22. Given the potential differences between exchange- and welfare-based valuation, it needs to be made very clear to the users of the ecosystem accounts that the values recorded in those accounts do not reflect welfare values and that important deviations can indeed exist. Depending on the policy or decision-making context, there may therefore be a need for the estimation of both exchange- and welfare-based values.

6.23. Current use of the national accounts, where monetary values do not necessarily reflect welfare generated, presents a situation analogous to that of the ecosystem accounts. For example, the values recorded in the national accounts for the production and consumption of education do not reflect the full welfare arising from that consumption, which is especially the case when education is provided by the public sector. Further, the use of exchange values to underpin macroeconomic modelling and measurement is accepted, as is the relevance of estimating welfare values in decision-making on, for example, the assessment of costs and benefits of additional investments in the education system.

6.24. Since the broad objective of ecosystem accounting is to support policy analysis and decision-making in practice, one issue that warrants further discussion and investigation is whether a complementary set of ecosystem accounts in monetary terms might be compiled using non-exchange value-based concepts. In accordance with the underpinning logic, those complementary accounts could be based on the same biophysical accounts (for ecosystem extent, condition and service flows), with alternative valuation concepts then being applied to support particular policy contexts. Discussions would need to consider not only the relevance and feasibility of such an approach but also how a set of complementary accounts would relate to the set of exchange value-based accounts.

6.3. Relevant data and source materials

6.3.1. Introduction

6.25. In terms of implementation, valuation exercises generally require, in the first instance, estimation of physical flows of ecosystem services. Those flows are then multiplied by a relevant value so that their monetary value can be estimated. Information on physical flows of ecosystem services is thus of direct relevance.

6.26. In terms of estimating values, this will usually involve a combination of approaches to analysing ecosystem services. From an aggregate perspective, the common starting points will be information from national accounts on production and income, economic statistics, trade data, tourism activity statistics, price index data and similar types of statistical and administrative data. While these data sets will not provide direct estimates of values for ecosystem services, they will provide a strong foundation for understanding the relative economic significance of a range of ecosystem services, particularly provisioning services and some cultural services.

6.27. For some services, valuation requires an understanding of spatial patterns of supply and use of ecosystem services. This is particularly the case for regulating services. Often, supply and use take place at distinct locations. For example, a forest may filter the air, while the persons using this service may be living near the forest. It should be noted that in cases where a fully spatial approach is pursued, there is also a need to allocate aggregate values of services spatially in order to produce maps of ecosystem services values (e.g., Remme and others, 2015; and Sumarga and Hein, 2014).

6.28. Where the resources required to undertake primary data collection are not available, it will be necessary to track down valuation studies that include estimated values for the relevant ecosystem service for particular ecosystem types. There are a number of databases that are the repository of relevant studies, including the Ecosystem Service Valuation Database (ESVD) which has built on the original work carried out within the framework of the TEEB initiative, the Environmental Valuation Reference Inventory (EVRI) database, and the Ecosystem Valuation Toolkit, which underpins the work of the organization Earth Economics.[42]

[42] A useful link to these and other valuation databases can be found at the Ecosystem Services Partnership website (www.es-partnership.org/services/data-knowledge-sharing).

6.29. Since the available studies do not provide a complete coverage of all locations or all ecosystem types, the application of the results from those studies will require careful consideration. Generally, it will be necessary to apply benefit transfer methods through which the results from one study are applied in other contexts. The critical question centres on the extent to which the contexts are comparable based on: (a) similarity of ecosystem assets and their services; (b) purpose of valuation and context for decision-making; and (c) similarity of likely institutional arrangements. In addition, it will be important for there to be an understanding of the connection to the underlying biophysical data and the scale at which those data have been estimated, for example, through biophysical modelling. A range of approaches to benefit transfer are available, with some being preferable to others. Chapter V of SEEA EEA provides an introduction to this subject; a more extensive discussion of alternative benefit transfer methods can be found in, for example, Plummer (2009) and Barton, Traaholt and Blumentrath (2015).

6.30. A general caveat with respect to the use of existing studies for the valuation of ecosystem services (which applies equally well to benefit transfer approaches) is that such sources are usually not explicit regarding the valuation concept being applied. Hence, it is often unclear whether the approaches, estimates and recommendations are suitable for ecosystem accounting purposes in terms of measuring exchange values. Nonetheless, in conjunction with the discussions in SEEA EEA, chapter V, those sources should provide a reasonable starting point for investigating the issue of valuation of ecosystem services for ecosystem accounting.

6.31. The process outlined here for the valuation of ecosystem services can be applied to the estimation of the value of ecosystem services in monetary terms for a single ecosystem service arising from a single ecosystem asset or ecosystem type. However, within an SEEA EEA context, the aim is, generally, to estimate values for multiple ecosystem services across multiple ecosystem assets and ecosystem types. In cases where the scope of compilation is enlarged to this extent, it is possible to compile an ecosystem services supply and use account in monetary terms by applying the valuation techniques described in subsection 6.3.2. This account has the same structure as the ecosystem services supply and use account in physical terms as presented in table 5.1. Thus, estimates for individual ecosystem services are presented in the same table and those estimates are recorded for both the supplying ecosystem type and the receiving users. An understanding of the ecosystem services supply and use account in physical terms will be appropriate—and likely necessary—to ensure the best compilation of the account in monetary terms. In principle, aggregation across ecosystem services and ecosystem types is possible even where different valuation techniques are used, provided the different techniques are focused on applying the same valuation concept. However, it should be recognized that different techniques may generate substantively different estimates of value; hence, whatever technique is used, care should be taken in quality-assuring all estimates.

6.32. Additional guidance on applying valuation in national accounting contexts can be found in materials issued by the UNEP Ecosystem Services Economics Unit, materials developed within the framework of the TEEB initiative, work being undertaken within the WAVES project and the discussion of valuation within the context of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Table 6.1
An overview of valuation techniques and their use in ecosystem accounting

Valuation technique	Description	Comments	Suitability for valuation of individual ecosystem services	Applicable for the following ecosystem services
Unit resource rent	Prices determined by deducting costs of labour, produced assets and intermediate inputs from market price of outputs (benefits)	Estimates are affected by property rights and market structures associated with production. For example, open-access fisheries and markets for water supply often generate low or zero rents	**Appropriate in principle**, but care is needed to ensure that residual estimated through this approach is limited to the target ecosystem service	Provisioning services involving harvest or abstraction (of timber, fish, crops, livestock, etc.) Potentially, cultural services such as recreation provided by established businesses
Production function, cost function and profit function methods	Prices obtained by determining contribution of the ecosystem to a market-based price, using an assumed production, cost or profit function	In principle, analogous to resource rent approach but, generally, can be better targeted to focus only on specific ecosystem services and models that are better able to take into account ecological connections. However, likely to be more data-intensive and require use of benefit transfer methods for higher-level aggregates	**Appropriate,** provided market-based price being decomposed refers to a product rather than an asset (e.g., value of housing services rather than value of a house)	Prices for all types of ecosystem services may be estimated using this technique provided an appropriate production or similar function can be defined, which requires that the ecosystem services be direct inputs into the production of existing marketed goods and services. The technique is likely to be most relevant in estimation of prices for provisioning services and certain regulating services that are inputs into primary production (e.g., water regulation)
Payment for ecosystem services (PES) schemes	Prices obtained from markets for specific regulating services (e.g., carbon sequestration)	Estimates will be affected by type of market structure put in place for each PES (see SEEA EEA, paras. 5.88–5.94)	**Possibly appropriate,** depending on nature of the underlying institutional arrangements	Price information most applicable to valuation of regulating services (e.g., carbon sequestration), since those services are the most common focus of PES schemes
Hedonic pricing	Prices estimated by decomposing value of an asset (e.g., dwelling(s) and the underlying land) into its characteristics, and pricing each characteristic through regression analysis	Highly data intensive. Separating effects of different characteristics may be difficult, unless there are large sample sizes	**Appropriate in principle**, if an individual service can be identified. Used heavily in pricing of computers in national accounts	Most commonly applied within the context of decomposing house and land price information and therefore relevant for ecosystem services that impact those prices (e.g., access to green spaces, amenity values and air filtration). Attribution of estimated prices to supply location presents a challenge
Replacement cost	Prices reflect estimated cost of replacing a specific ecosystem service using produced assets and associated inputs	Requires an understanding of ecosystem function underpinning supply of the service and the ability to find a comparable "produced" method of supplying the same service	**Appropriate,** under assumptions that: (a) estimation of costs reflects qualities of the ecosystem services being lost; (b) this is a least-cost treatment; and (c) society would be expected to replace the service if it were removed. Assumption (c) may be tested using stated preference methods and should take into account potential scale issues associated with replacing the service	Entails assumption that a service can be replaced, i.e., that a man-made alternative can be developed. This engineering-type focus signifies, in general, that this method would be applicable to various regulating services (e.g., water regulation, water purification and air filtration)
Damage costs avoided	Prices estimated in terms of value of production losses or damages that would occur if ecosystem services were reduced or lost owing to ecosystem changes (e.g., pollution of waterways)	Determination of value of contribution/impact of an individual ecosystem service may pose a challenge	**Appropriate,** under assumptions that: (a) estimation of damage costs reflects specific ecosystem services being lost; (b) there is a continuing demand for the services; and (c) estimated damage costs are lower than potential abatement or replacement costs	Similar to replacement cost, the focus is generally on services provided by ecosystems that are lost owing to the impact of human activity on environmental condition, particularly through pollution. Regulating services are likely to be the type of services most commonly estimated using this method

Table 6.1 (continued)

Valuation technique	Description	Comments	Suitability for valuation of individual ecosystem services	Applicable for the following ecosystem services
Averting behaviour	Prices estimated based on individuals' willingness to pay for improved health or to avoid undesirable health outcomes	Requires an understanding of individual preferences. Linking activity of the individual to a specific ecosystem service may be difficult	**Possibly appropriate,** depending on actual estimation techniques. Applicability of this method relies on the awareness of individuals of impacts arising from environmental changes	
Restoration cost	Refers to estimated cost required to restore an ecosystem asset to an earlier, benchmark condition Should be clearly distinguished from replacement cost method	Main issue arises from fact that costs are related to a basket of ecosystem services rather than to a specific ecosystem service. More often used as a means of estimating ecosystem degradation; however, there are issues arising from its application in this context as well	**Likely inappropriate**, since it does not determine price of an individual ecosystem service but may serve instead to inform valuation of a basket of services	
Travel cost	Estimates reflect price that consumers are willing to pay to visit recreational sites	Key challenge is to determine actual contribution of the ecosystem to total estimated willingness to pay. There are also many applications of that method, entailing various assumptions and techniques, with the common objective of estimating consumer surplus. Some travel cost methods include value of household's travel time, which would be considered outside the scope of production boundary used for accounting purposes	**Possibly appropriate,** depending on actual estimation techniques and whether approach provides an exchange value, i.e., excludes consumer surplus. It is important to specify that total actual travel costs is not a direct measure of the value of the ecosystem services, but the demand curve associated with the travel costs may be used to derive exchange values directly (estimation of demand curve constitutes travel cost method)	Related to valuation of recreational ecosystem services
Stated preference	Prices reflect willingness to pay, derived from either contingent valuation studies or choice modelling	These approaches are generally used to estimate consumer surplus and welfare effects. Biases, which can potentially be introduced into the range of techniques used, should be taken into account	**Inappropriate**, since it does not measure exchange values. However, while direct values derived from applying stated preference methods are not exchange values, it is possible to estimate a demand curve from this information, which may be used in determining exchange values for ecosystem services	
Marginal values from demand functions	Prices estimated by utilizing an appropriate demand function and setting price as a point on curve corresponding to that function: (a) using observed behaviour to reflect supply (e.g., visits to parks); or (b) modelling a supply function	Entails use of demand functions estimated through travel cost, stated preference or averting behaviour methods. Use of supply functions underpins what is referred to as the simulation exchange value approach (see Campos and Caparrós, 2011)	**Appropriate**, since aim is to measure exchange values directly. However, creation of meaningful demand functions and description of hypothetical markets may pose a challenge	In principle, may be applied for many types of ecosystem services but is most likely to be relevant in the estimation of values for regulating and cultural services

6.3.2. Potential valuation techniques

6.33. A number of valuation techniques have been considered appropriate for measuring exchange values. At the same time, there is ongoing discussion on this topic aimed at building a higher-level understanding of the use, for accounting purposes, of standard non-market environmental valuation techniques, a number of which are outlined in SEEA EEA, chapter V. An updated overview of valuation techniques is provided in table 6.1.

6.34. Table 6.1 lists several standard techniques in the left-hand column following the structure of the discussion in SEEA EEA. Ideally, it should be possible to provide more specific guidance on valuation techniques by type of ecosystem service, which, in the case of the table, would entail inclusion of different ecosystem services in that left-hand column. At this stage, while clear-cut advice on valuation techniques recommended for individual ecosystem services has not been considered or developed, the intention is to move in such a direction; and progress in discussions on the classifications of ecosystem services will lend considerable support to achieving this objective. A common classification of individual ecosystem services, which will encompass consistent descriptions of individual ecosystem services and clarify the relationship with associated benefits, would simplify the process of selecting those valuation techniques that are most relevant. Indeed, it is clear that different descriptions of ecosystem services can lead to quite different valuations.

6.3.3. Alternatives to direct monetary valuation

6.35. The discussion in the present chapter is focused on the direct valuation of individual ecosystem services. In some circumstances, complementary information concerning economic activity associated with certain ecosystem services may provide a broader picture of the economic relevance, or value, of those services.

6.36. For instance, governments may be interested not only in the resource rent generated by ecosystems under current management, but also in, for example, the net value added and employment that is generated in sectors dependent upon services provided by an ecosystem, such as the fisheries or the nature-based tourism sector. Since net value added indicates the return on the combined use of ecosystem assets, produced assets and labour, it provides a broader insight into the economic significance of ecosystems than that provided by resource rent alone.

6.37. Furthermore, it is to be noted that measures of value added are less affected by the problem of zero rent generated by open-access common-pool ecosystem resources, as there is still a return on labour and produced assets in such systems. Crucially, value added also provides a better measure of the relevance of ecosystem services in situations in which there are few alternative sources of income. For example, in the case in which a significant part of the population is involved in fisheries or livestock raising, and few alternative employment options are available, the resource rent may sharply underestimate the economic significance of the resource for people in the area.

6.4. Valuation: key challenges and research activities

6.38. There are a wide range of challenging issues associated with valuation, some of which have been mentioned in earlier sections. The present section focuses on the issues that are most commonly confronted, some of which are particularly significant focuses of research work.

6.39. *Target of valuation*. In SEEA EEA, the ecosystem accounting model (see chap. II) clearly distinguishes between ecosystem services and the benefits to which they contribute. Particularly for provisioning services, it is not uncommon for the market price of the extracted good (e.g., fish caught or timber harvested) to be considered equivalent to the value of the ecosystem service; but in fact, the market price reflects the value of the benefit. Estimating the appropriate value of the associated ecosystem service requires deducting the costs of extraction and harvest, with the residual reflecting the ecosystem contribution.

6.40. In the case of timber harvest, for example, there is commonly a price for the logged timber—perhaps a roadside price—which should be sufficient to cover the costs of felling (i.e., costs of labour, fuel, equipment, land management, etc.), as well as any payments made to the owner of the forest for the right to harvest the timber, commonly referred to as the stumpage price. The value of the ecosystem services in that case is not the roadside price after felling, but rather the stumpage price, which is equivalent to the residual after deducting the costs of extraction.

6.41. In some cases (for example, that of abstracted water or open-access fishing), this residual may be a very small or negative quantity. Consequently, the implied value of the ecosystem service may be very low, zero or negative from an exchange-value perspective. A number of different cases can be identified. In the case of water, for example, the resource rent is often near zero, as there is commonly no competitive market for distributed water, and prices are so regulated as to cover only the costs of supplying it to customers. In the case of open-access fishing, the lack of defined property rights is the key driver for low values. In recreational hunting, the costs are often higher than the potential sale price of the game meat, but the difference between costs and sale price reflects the willingness of the hunter to engage in the activity and hence may be an estimate of the recreational value of hunting.

6.42. Different valuation approaches may, depending on the situation, be considered as alternatives to resource rent techniques, for example, use of replacement costs in the case of water or the costs of hunting licences in the case of recreational hunting (see Remme, Schröter and Hein, 2014). Most problematic is selecting an approach in the case of open-access, common-pool resources. It is to be noted that while the benefits produced in that case (e.g., fish or water) still have market prices, the ecosystem services are valued implicitly at near zero, implying that ecosystem degradation would be so valued as well. Further discussions on potential approaches to accounting in those situations are encouraged.

6.43. *Relating ecosystem assets to values for ecosystem services*. The issue of distinguishing between valuation of ecosystem services and valuation of ecosystem assets, and the related issue of valuing ecosystem degradation, are important considerations. Within ecosystem accounting, the valuation of ecosystem assets, which reflects the overall value of a given spatial area, is estimated by aggregating the net present value of all relevant ecosystem services. Those issues are discussed in chapter VII.

6.44. In pricing theory, the capital costs associated with the supply of ecosystem services, that is, the costs of any ecosystem degradation, should influence the price set for the outputs. However, many approaches to valuation assume implicitly that the use of the associated ecosystem asset is sustainable, thus setting the capital costs at zero. The need to incorporate the impact of degradation on the prices of ecosystem services is recognized as a challenging issue (see Bateman and others, 2011) that has yet to be resolved.

6.45. *Valuation of subsistence production*. In a number of situations, there may be significant flows of ecosystem services associated with subsistence agriculture, forestry and fisheries, that is, when the outputs from growing and harvesting activities are not sold on markets but directly consumed by households. A broad range of products may be relevant in this regard, including all types of non-timber forest products. Following the conceptual scope of the SNA, the production associated with these activities should be included in the national accounts estimates of output, with exchange values estimated on the basis of the prices of similar goods sold on markets. *Measuring the Non-Observed Economy: A Handbook* (OECD and others, 2002) provides guidance on measurement approaches in this area. Techniques described in the preceding paragraphs for similar provisioning services, such as the unit resource rent and production function approaches, can be used for the valuation of the associated ecosystem services on the basis of these estimated market prices.

6.46. *Valuation of intermediate services*. The focus of valuation in SEEA EEA, and in the majority of other studies, is on final ecosystem services. That focus supports an understanding of the interactions between ecosystem assets and users (i.e., economic units including households). However, if the valuations of final ecosystem services are attributed to specific ecosystem assets, that may imply that those assets supplying final ecosystem services have a particularly high value relative to ecosystem assets that do not supply final services directly. Thus, where there are important dependencies between ecosystem assets in the supply of a final ecosystem service, ignoring the value of intermediate services may provide misleading information on the relative importance of certain ecosystem assets. At the same time, there are significant measurement challenges in estimating the required ecological production functions, and this area of measurement attests to a need for further research and testing. Description and measurement of ecological production functions would chart an important pathway towards achieving an understanding of the connections between ecosystems.

6.47. *Valuation of regulating services*. For most provisioning services, a connection to the market values of benefits exists, and it can provide a basis for measurement. That is also true for some—but by no means all—cultural services, such as those related to economic activity in tourism and recreation. However, in the area of regulating services, such connections to marketed benefits are unusual. Indeed, it can be difficult to appropriately define and measure the actual physical flow of a regulating service because often the service is simply part of ongoing ecosystem processes rather than a function of direct human activity (e.g., air filtration or carbon sequestration). The primary challenge presented by valuation of regulating services is thus to articulate the link between those services and human activity so as to ensure that the application of valuation techniques has a firm foundation.

6.48. *Measurement of non-use values*. From a societal perspective, an important component of the value of ecosystems comprises the non-use values that should, in principle, be captured in various cultural services provided by ecosystem assets. Those include existence values, based on the utility derived from knowing that an ecosystem exists; altruistic values, based on the utility derived from knowing that someone else is benefiting from the ecosystem; and bequest values, based on the utility derived from knowing that the ecosystem may be used by future generations (see also SEEA EEA, para. 5.28 (d)). While at present there are relatively few studies in that area of valuation, it is a particular focus of discussion within the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services programme of work.[43] Further, from an ecosystem accounting perspective, even if the associated ecosystem services are considered to be within scope, the extent to which non-use values can be captured through application of the concept of exchange value remains an open question.

[43] See www.ipbes.net/work-programme

6.49. *Valuation of ecosystem assets with respect to land*. The value of land, including agricultural land, that is commonly traded in markets is an important consideration within the context of estimating the value of ecosystem assets at exchange values. Whether values of land incorporate the value of some ecosystem services depends on the circumstances. They are unlikely, however, to capture the value of all of the ecosystem services, particularly those that can be characterized as public goods. Further, market-based land values incorporate elements of value that are not dependent on ecosystems, such as the prospects for property development or the capitalization of farm subsidies. Consequently, when considering the integration of ecosystem asset valuations into existing national accounts balance sheets, some adjustments are required to ensure that there is no double-counting or gaps in valuation for the estimation of total net wealth.

6.50. *Valuation of biodiversity and resilience*. In SEEA EEA, biodiversity and resilience are regarded primarily as characteristics of ecosystem assets and not as ecosystem services. Consequently, as biodiversity and resilience are not separately valued using the general approach outlined here, their relative contributions to the value of ecosystems as a whole are unlikely to be identifiable. Further consideration therefore needs to be given to how those characteristics of ecosystem assets may be incorporated into valuations, including in terms of how biodiversity and resilience feature in the description of ecological production functions.

6.51. *Channels of ecosystem services*. Underlying many of the challenges posed by valuation have been differences in viewpoints regarding the conception of value and its application. As noted earlier, one source of those differences has been the divergent perspectives of accountants and economists on non-market valuation. However, a potential way forward has emerged from ongoing World Bank-led valuation research efforts aimed at facilitating both a better understanding and a bridging of those differences. That has been achieved through identification of a framing of valuation—a framing that is not known to accountants but is widely understood by environmental economists—which considers valuation within the context of various channels, each of which links the environment with business, individuals and society. Freeman, Herriges and Kling (2014) identify the following three main channels:

- *Channel 1—Inputs to production*: ecosystem services used as inputs to economic production. The many examples include water regulation and water purification services, which are inputs to those economic (producing) units requiring a supply of clean water alongside other factors of production. Importantly, this channel is not limited to provisioning services, as a range of regulating and cultural services are also used as inputs to production;

- *Channel 2—Inputs to household consumption*: ecosystem services that act as joint inputs to household consumption, that is, use of those services in combination with, or as a substitute for, expenditure on produced goods and services results in an output, that is, a "product" for consumption[44] by a given household. In such cases, as the ecosystem services and the market goods or services are complementary, or substitute, inputs, expenditure on those market goods or services provides an indicator of the value placed on the ecosystem services. For example, ecosystem services can be combined with human inputs (in the form of hotels, restaurants, walking paths, etc.) to produce recreational and tourism benefits. On the other hand, ecosystem services can be a substitute for market

[44] Typically, in environmental economics, that is referred to as "household production". The term "consumption" is used here because it is the conventional terminology in accounting.

expenditure. For example, air purification services can substitute for the purchase of a produced good that filters the air;[45]

- *Channel 3—Inputs to well-being*: ecosystem services used as inputs that contribute directly to household well-being. To generate benefits, those services are consumed directly from nature without first serving as inputs to some form of economic production or household consumption. Inputs of that type, which tend to be comparatively abstract and somewhat intangible, include ecosystem services that are valued based on what is usually referred to as passive or non-use.

6.52. The presentation of the channel-based approach to categorizing ecosystem services for valuation purposes is well developed in the environmental-economic literature. That approach, in contrast to the externality-based framing of valuation that is commonly applied in environmental economics, is much more directly aligned with the framing of valuation by national accountants. Indeed, the various channels can be viewed as conceptually equivalent to the cells within a supply and use account, each of which records a distinct link between a supplier and a user in the context of the channels-based approach, the supplier would be an ecosystem asset and the user, an economic unit.

6.53. The key conclusion drawn from discussions in this area is that the choice of valuation technique cannot be based solely on type of ecosystem service, which is not the case for the most widely utilized approach to date. The choice of valuation technique must also take into account the characteristics of the user. While, in many cases, that may not make a significant difference with respect to the technique ultimately chosen, consideration of the user does ensure a more satisfactory valuation context from a national accounting perspective.

6.54. As research on the framing of valuation in the context of channels is ongoing, that technique is not further elaborated in the *Technical Recommendations*. The discussion is aimed at encouraging the continued engagement of ecosystem accounting compilers with the environmental economics valuation community as a means of advancing efforts to meet the challenge of valuing ecosystem services.

6.5. Recommendations for the valuation of ecosystem services

6.55. A substantial amount of work remains to be done to advance the valuation of ecosystem services within the context of ecosystem accounting. At one level, there is a need to continue the discussion on the role of valuation, both in general terms and with respect to accounting. The main challenge is to provide the appropriate context for that discussion, as many misunderstandings associated with the relevant issues do commonly arise. A key message would be that valuation may be carried out for different purposes, and that the best approach to addressing certain issues may not rely on information presented in monetary terms.

6.56. At a second level, there is a need for an understanding of the concept of exchange values as formulated for accounting purposes and the development, or adjustment, of valuation techniques to support estimation of those values. A possible path forward would entail improving the capacity to distinguish between: (a) the relevant valuation techniques in cases in which ecosystem services targeted for valuation can be linked to existing market prices with relative ease; and (b) the techniques that are applicable in cases in which the targeted ecosystem services are related to public goods. These two principal cases pose different challenges.

[45] Firms may also undertake defensive expenditures of that type, that is, they may purchase substitute goods to defend against an environmental burden, which exists in the absence of some ecosystem service. The value of this service may then be approximated by estimating how the cost of producing current output changes as a result of a small change in provision of the service. Given that it involves the production side of the economy, the pathway should be classified under channel 1 rather than channel 2, which covers household consumption.

6.57. One of the most important ecosystem accounting challenges is to ensure that users of the monetary ecosystem accounts understand the valuation concepts applied. Specifically, they should understand that the accounts do not provide an estimate of the "value of nature" or even of the "economic value of ecosystems". Instead, what those accounts do provide is an estimate of the monetary value of the contribution of ecosystems to economic production and consumption, at least to the extent that a comprehensive set of ecosystem services has been used and a valuation of those services is possible.

6.58. In cases in which ecosystem services can be linked relatively easily to market prices (e.g., provisioning services and tourism-related services), an important part of the information required for valuing the services may already be available in the national accounts. For those services, valuation specifies the contribution of the ecosystem to the related benefits already included in the national accounts in monetary terms. Following table 6.1, application of a resource rent-based valuation approach may be appropriate for such services, which should include noting the potential challenges associated with the estimation of low or negative resource rents. 2008 SNA and *Measuring Capital: OECD Manual* (OECD, 2009) provide detailed guidance on how intermediate inputs, labour and fixed capital should be costed, including, for example, guidance on estimation of rates of return to produced assets.

6.59. The SEEA EEA approach involves the combination of tabular and mapped information. Producing maps for ecosystem services that are valued based on information found in the national accounts generally entails spatial allocation. This is straightforward in some cases, for example, that of forests providing timber to a logging company. In other cases (e.g., in which the resource rent generated in the tourism sector is being allocated to ecosystems), some modelling of spatial interactions between ecosystem users and the ecosystem asset is required.

6.60. In the case of public services, including most regulating services that are not captured in the national accounts, spatial models for the physical flows of the ecosystem services involved provide the basis for valuation. There may be significant uncertainty, however, associated with both the physical models, as discussed in chapter V, and the unit values for those services. Further, different regulating services require different valuation methods: replacement cost methods can be applied based on the least-cost alternative if it can be reasonably assumed that the service would indeed be replaced if lost. This method is relevant, for example, in the case of the flood protection service of coastal or riparian ecosystems in densely populated areas. When it cannot be assumed that the service would be replaced, an avoided-damage cost method may be appropriate (see table 6.1). There has also been ample experience with the application of another valuation method, namely, hedonic pricing, which can be used to value, inter alia, the cultural service underpinning the positive amenities that people enjoy through contact with nature, as in the case of estimating the additional value of a house attributable to that house's having a good view or to its being close to a green space.

6.61. Other valuation methods, although applied less frequently, have the potential to widen the range of available choices for ecosystem accounting. The simulated exchange value approach and the travel-cost method, for example, can be used to estimate demand curves, which would facilitate a more comprehensive inclusion of tourism and recreation in the ecosystem accounts. Well-functioning payment for ecosystem services schemes may support estimation of the demand and supply for ecosystem services and associated prices from a partial market equilibrium perspective.

However, the following question still needs to be examined: under what conditions do the prices paid for ecosystem services in such schemes truly reflect exchange values.

6.62. In general, further efforts are needed to estimate exchange values of ecosystem services in practice, for a basket of ecosystem services across a range of ecosystem types. There is work being carried out in pursuit of this goal (e.g., Remme, Schröter and Hein, 2014; Sumarga and Hein, 2014), but further testing is required. The environmental economics literature attests to the ample experiences that exist in applying the hedonic pricing, replacement cost and damage costs avoided techniques—experiences that can be built upon. However, with regard to, for example, the simulated exchange values and travel cost methods and payment for ecosystem services pricing schemes, there is a need within the context of accounting for further research before such valuation approaches can become more standardized.

Chapter VII
Accounting for the value and capacity of ecosystem assets

Key points

- The ecosystem monetary asset account records the monetary value of the opening and closing stocks of all ecosystem assets within an ecosystem accounting area and additions and reductions in those stocks.
- Estimates of the monetary value of ecosystems are compiled using the concept of exchange value developed in chapter VI. That facilitates integration with the values of other assets such as buildings, machinery and equipment, and financial assets.
- In most cases, monetary values of assets are estimated based on the net present value of the expected future flows of all ecosystem services generated by an ecosystem asset. That requires understanding the likely pattern for the supply and use of each ecosystem service and recognizing that the patterns of supply of various ecosystem services generated by a single ecosystem asset are likely to be correlated.
- The estimation of net present value also requires the selection of a discount rate, which can have a significant impact on the resulting valuations.
- A key basis for estimating the pattern of future flows of ecosystem services is understanding the relationship between those flows and the condition of the ecosystem asset. The relationship between service flows and ecosystem condition is reflected in the concept of ecosystem capacity, which can be measured in both physical and monetary terms.
- The measurement of ecosystem capacity is also linked to the measurement of ecosystem degradation, that is, the decline in the condition of ecosystem assets as a result of economic and other human activity.
- Further testing and research are required in many areas related to measurement of the monetary value and capacity of ecosystem assets. That includes the application of NPV techniques for ecosystem assets, the estimation of future patterns of ecosystem service flows, the measurement of ecosystem capacity, and the valuation and attribution of ecosystem degradation.

7.1. Introduction

7.1. The discussion of accounting for the monetary value and capacity of ecosystem assets in the present chapter, and the associated discussion of integration of ecosystem accounting information with standard national accounts in chapter VIII, are consistent with: (a) the way in which national accountants make the connection between the national accounts and ecosystem information; and (b) the literature on wealth accounting (e.g., United Nations University—International Human Dimensions Programme on Global Environmental Change (UNU-IHDP) and UNEP, 2015; Hamilton and Clemens, 1999) as related to the valuation of natural capital. Given the connections to national and wealth accounting, some initiatives have adopted the position that accounting for ecosystem assets in monetary terms is the underlying motivation for measurement in the area of measurement of ecosystems (e.g., the accounting work conducted within the framework of the Natural Capital Committee (United Kingdom)). However, the discussions in SEEA EEA and in the *Technical Recommendations* recognize that that is not the only measurement objective that is appropriate.

7.2. Underpinning accounting for ecosystem assets in monetary terms is the view that the estimation of the monetary value of an ecosystem asset can be carried out in the same way as the estimation of the monetary value of other assets, that is, in terms of the future flow of income attributable to that asset. For most economic assets, that value is estimated for SNA-related purposes based on the recording of actual transactions in assets (e.g., the sale and purchase of buildings and equipment). Where the markets for specific assets are thin or do not exist, as is the case for ecosystem assets, the SNA proposes alternative valuation techniques, including the use of the discounted flows of future income (see SEEA EEA, sect. 5.4, for a summary of such techniques). The present chapter discusses approaches to and the challenges associated with undertaking accounting for ecosystem assets in monetary terms.

7.3. The standard logical basis for approaching this facet of ecosystem accounting entails: (a) identifying the basket of ecosystem services supplied by the specific ecosystem asset; (b) estimating the expected ecosystem service flows, that is, the flows of each type of ecosystem service that are considered most likely to occur based on current expectations of the use of the ecosystem; and (c) applying appropriate prices to each flow of ecosystem services and discounting each flow to the current time period. The discounted value of future flows represents the net present value of ecosystem assets. That approach, which is guided by standard capital accounting theory (see OECD, 2009), recognizes the direct connection between the valuation of ecosystem services and that of ecosystem assets.

7.4. The level of "expected ecosystem service flow" (a concept introduced in SEEA EEA, para. 2.40) may be higher or lower than the level of ecosystem flows that might be considered sustainable, that is, in the estimation of ecosystem asset values at any point in time, sustainable use should not be assumed. Such an assumption implies that ecosystem assets cannot be subject to ecosystem degradation. At the same time, it may be of considerable interest to determine the difference between the level of expected ecosystem service flows and the level of flows that would be sustainable, that is, the level that would imply no loss in ecosystem condition in the future. That is directly linked to the concept of ecosystem capacity. Given the importance of those issues, the concepts and measurement of ecosystem capacity and ecosystem degradation are discussed in the present chapter at some length, with the general conclusion being that further discussion and investigation are required if a more broadly shared understanding of the issues is to be achieved.

7.2. Ecosystem monetary asset account

7.2.1. Description of the account

7.5. The ecosystem monetary asset account records the monetary value of opening and closing stocks of all ecosystem assets within an ecosystem accounting area, as well as additions and reductions in those stocks. Since they provide a consistent basis for comparison, estimates of ecosystem assets in monetary terms are useful for decision-making on alternative uses of ecosystem assets. In addition, estimates in monetary terms can be integrated with valuations of other types of assets to provide more complete assessments of net wealth. A decline in value of ecosystem assets at aggregated scales (e.g. in EAA) may point to unsustainable ecosystem use.

7.6. The relevant accounting structure for the ecosystem monetary asset account is displayed in table 7.1. The structure has been simplified and allows for only very basic asset account entries. If greater detail is required to account for changes in assets, particularly those related to provisioning services, then additional row entries—including growth in and normal loss of stock, catastrophic losses (e.g., changes due to natural disasters), upward and downward reappraisals, and reclassifications—can be incorporated, following the structure of the monetary asset account in table 5.3 of SEEA Central Framework. Using a separate entry, the account records changes in the value of the stock of ecosystem assets, between opening and closing, that are due to revaluations, that is, changes in value that are due solely to changes in price rather than to changes in volume.[46]

7.7. Different presentations (column headings) are possible, given that the data are presented in monetary terms. That is, an asset account can be scoped and structured to refer to an individual ecosystem asset (e.g., a specific grassland), to a specific ecosystem type (e.g., all tree-covered areas) or to an ecosystem accounting area. Table 7.1 shows an account for an EAA by proxy ET.

7.8. The total value of a country's ecosystem assets can be incorporated in extended national balance sheets, as discussed in chapter VIII. Chapter VIII also provides an extended discussion of other facets of the integration of ecosystem accounts-based data into the standard national accounts, for example, for the derivation of degradation-adjusted measures of national income and the compilation of extended input-output tables.

[46] Following the SEEA Central Framework (para. 5.61), a change in the value of an ecosystem asset in response to a change in quality—due, for example, to a change in condition—is considered a change in volume rather than a revaluation.

Table 7.1
Interim ecosystem monetary asset account (currency units)

	Proxy ecosystem type (based on land cover)															
	Artificial surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree-covered areas	Mangroves	Shrub-covered areas	Regularly flooded areas	Sparse natural vegetated areas	Terrestrial barren land	Permanent snow and glaciers	Inland water bodies	Coastal water and intertidal areas	Sea and marine areas	TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Opening stock of ecosystem																
Addition to stock																
Reductions in stock																
Revaluations																
Closing stock of ecosystem assets																

7.9. Entries in the ecosystem monetary asset account extend beyond the measurement requirements of the ecosystem services supply and use account in monetary terms by incorporating the use of NPV techniques and assumptions regarding the flow of services in the future. That is, the focus is on the measurement of the value—and changes in value—of ecosystem assets, as distinct from flows of ecosystem services. It is assumed that the individual services are mutually exclusive and that their values can be aggregated. In some cases, the value of ecosystem assets for a selection of services may be gathered directly, for example, from observed land values.

7.10. The future flow of services depends, typically, upon the condition and natural regeneration of the ecosystem and future uses of ecosystem services. For example, the value of an ecosystem asset in relation to its ability to enable timber harvesting depends upon: (a) the standing stock of timber at a given moment; (b) the expected growth or regrowth of the timber stock, which, in turn, is a function of ecosystem condition indicators such as soil fertility; and (c) the expected demand for timber products.

7.11. Assuming that the net present value for each type of ecosystem service is separable, it is possible to consider the total value and changes in value for each ecosystem service flow separately. In light of the complex interlinkages characterizing the supply of ecosystem services, that assumption is a significant one. From an accounting standpoint, the effect of this assumption depends on the extent to which the factors affecting the future supply of services and the associated asset lives that underpin the NPV calculations are considered in an integrated and coherent manner. If those variables are estimated for each service independently, then it is likely that the assumption of separability will be problematic. Such concerns are reduced, however, if the potential linkages between services are taken into account.

7.12. For example, if carbon sequestration services are estimated under the assumption that a forest can sequester carbon over an infinite time frame, while for the same ecosystem asset, rates of timber provisioning are estimated under the assumption that the forest will be depleted within a limited time frame (e.g., 30 years) with no regeneration, then the two estimates of expected service flows should be considered internally inconsistent. In many cases, it is likely that asset lives for provisioning services involving harvest or extraction will provide an upper bound to the asset lives for other services, and hence the asset life should be applied in the estimation of all expected ecosystem service flows.

7.13. For provisioning services, such as timber extraction, accounting for additions and reductions is conceptually straightforward. In that case, the value of those services will reflect a resource rent (taking into account the estimation challenges noted in chap. VI). Advice on accounting for the changing value of provisioning services is therefore conceptually analogous to the advice provided in SEEA Central Framework and the SNA on accounting for individual environmental assets. Application of that approach is possible since the underlying physical flows (e.g., of timber resources) can be accounted for using a single metric.

7.14. For regulating and cultural services, the link to underlying physical flows may be less clear-cut. In the case of regulating services, the challenge stems from the fact that the supply of the service depends not only upon the extent and condition of the ecosystem, but also on other factors that do not remain stable over time. For example, while air filtration is a function of the extent and type of vegetation and its leaf area index, it is also influenced by expected air pollution levels, which can be spatially and temporally heterogeneous. Thus, the higher the concentration of atmospheric particulate matter, the greater the amount of particulate matter that is normally captured by the vegetation.

7.15. In addition, most regulating services depend upon a variety of ecosystem characteristics and processes, each of which provides only limited information on the capacity of the ecosystem to supply the service over time. In the case of air filtration, for example, relevant indicators may reflect ecosystem characteristics such as leaf area index per basic spatial unit, while indicators for the water regulating service provided by forests may reflect outputs of the ecosystem, such as the amount of water made available for irrigation throughout the year. Establishing accounting entries for changes in ecosystem asset values related to regulating services is therefore not a straightforward process.

7.16. The challenge with respect to cultural services may be to find physical data appropriate for quantifying those services in terms of the underlying ecosystem assets. Cultural services can entail either a passive interaction with an ecosystem (e.g., enjoyment of its amenities through consumption of information obtained from various media) or active interaction (e.g., an actual visit). Thus, the relationship between the condition of the ecosystem in physical terms and the supply of cultural services may be difficult to define in general terms. For example, in the case of recreation, a large number of people may be allowed access to a natural park but, at some point, there will be a decline in the quality of the individual's recreational experience because of overcrowding.

7.17. From an overall perspective, policy-relevant physical indicators for ecosystem assets can be defined for most provisioning services, while indicators for regulating services are harder to define and are an active area of research and testing. Indicators for cultural services are most in need of further development at this stage. It is appropriate to undertake the selection of those indicators and consider how to measure them in combination with the development of indicators of condition.

7.18. In a fully spatial approach for which sufficient data are available, it is possible to map ecosystem asset values and, where time series are available, to identify areas subject to declines in the value of ecosystem assets.

7.19. In terms of implementation, it is envisaged that, in the first phases of ecosystem accounting, ecosystem monetary asset accounts should focus on estimating the opening and closing values of the stock of ecosystem assets within the framework such as the one in table 7.2, where the row entries are individual ecosystem services and the aggregate opening and closing values for each service are provided in the columns. Where possible, the accounts could be extended and values attributed to ecosystem types. Further, where price effects can be distinctly observed, it may be appropriate to identify the revaluation component of the total change in value so that a real measure of change in ecosystem asset values can be provided.

7.20. While, in general, the opening and closing values are the values at the beginning and end of an accounting year, longer or shorter accounting periods may also be used.

Table 7.2
Possible presentation of ecosystem asset values by type of ecosystem service

	Opening value (currency)	Closing value (currency)
Ecosystem services (selected)		
Provisioning sevices		
Biomass accumulation		
Timber		
Crop		
Grass/fodder		
Fish		
Water abstraction		
Regulating services		
Carbon sequestration		
Water regulation		
Water purification		
Air filtration		
Nutrient/waste remediation		
Pest and disease control		
Soil retention		
Cultural services		
Enabling tourism and recreation		
Enabling nature-based education and research		
Enabling nature-based religious and spiritual experiences		
Total		

7.2.2. Measurement of net present value

7.21. The valuation of ecosystem assets, and the estimation of associated changes in the value of ecosystem assets, require the derivation of net present values for the flows of ecosystem services.[47] Setting aside the issues discussed in other chapters—on the measurement of the flows of ecosystem services in physical terms (chap. V) and the estimation of relevant values for ecosystem services (chap. VI)—there remain other measurement considerations that arise in estimating NPV. For a more detailed and comprehensive discussion on the application of NPV for natural resources within an accounting context, readers are referred to section 5.4 of SEEA Central Framework. A summary of that discussion and some additional items for considerations within the context of ecosystem assets in monetary terms are presented here.

7.22. First, an understanding is required of the expected asset life of the ecosystem, that is, of the length of time over which ecosystem services will be supplied into the future. Efforts in this regard should not be undertaken independently for each ecosystem service. In many cases, the supply of regulating and cultural services compete relative to the supply of provisioning services. In those circumstances, it is likely that the estimated asset life for provisioning services will provide the relevant upper bound under the asset life assumption. Where an ecosystem asset is being used sustainably,

[47] A closely related measurement approach entails the use of land expectations values commonly used in forest land valuations. The literature on that subject will be considered in future research.

that is, with no expectation of a decline in ecosystem condition, the asset life appropriate at the current estimation date are infinite. The estimation of asset lives is directly related to the discussion of ecosystem capacity and ecosystem degradation presented in sections 7.3 and 7.4, respectively.

7.23. In the derivation of macro-level estimates of national wealth, it is common to assume a generic asset life (e.g., 25 years) rather than to make estimates of asset lives that take into account the varied relationships between ecosystem condition and expected service flows for various assets (e.g., World Bank (2011)). Clearly this is more straightforward methodologically. It may also be rationalized at an aggregate level, since in cases where discount rates of greater than 5 per cent are used, the contribution of future income flows beyond 30 years to the total asset value diminishes to about 2 per cent at 5 per cent discount rates and to about 6 per cent at 10 per cent discount rates (see SEEA Central Framework, annex A5.2, table A5.1). That is, at higher discount rates, much of the value of ecosystem assets is captured in the first 25–30 years. However, since there is a strong correlation between the choice of asset life and the choice of discount rate, if a generic asset life is assumed, then compilers are encouraged to undertake estimations for a variety of asset life and discount rate alternatives so as to assess and convey the sensitivity of ecosystem asset values to these choices.

7.24. A priori, there is no generic asset life that is to be preferred, since it depends on the condition of the ecosystem asset and the expected patterns of use. Therefore, as far as possible within available resources, it is recommended that specific asset lives be explored, at least for different ecosystem types. Not only does such work provide a more robust estimate of those asset lives, but also the process serves as a form of data confrontation in terms of expectations regarding the supply of various ecosystem services and the potential changes in condition, taking into account various driving forces, for example, population growth.

7.25. Second, the derivation of NPV requires a description of the expected future flows of ecosystem services. Those flows may be affected by many factors, in particular ecosystem condition. It may therefore be useful for future flows in physical terms and future changes in values of those ecosystem services to be considered separately. A common assumption in national accounting for natural resources is that the resource rent per ton extracted (unit resource rent) remains constant over the remaining asset life; however, such an assumption should be considered only a default basis for estimation. An assessment of possible future trade-offs between various services is highly preferable.

7.26. Given that the aim is to provide the best possible estimate of expected flows—even when it is assumed that the unit resource rent, or, more broadly, the value per unit of ecosystem services, remains constant into the future—the past time-series of unit resource rents could exhibit some degree of volatility. In such cases, it is recommended that an average of recent periods (say from three to five years), be used as the basis for estimating future flows. However, when changes in unit resource rent occur that may be attributed to structural change (e.g., a change in regulations), averaging over time periods may not be appropriate. It should be made clear that, in general, basing the determination of asset values on expectations means that those values will be less reliable. It should also be noted that the framing for establishment of values based on expectations can also be applied to establishment of values based on alternative future scenarios (i.e., scenarios that may not be the most likely ones).

7.27. The use of bio-economic models may be of particular relevance in estimating asset lives. Those models, which take into account ecological dynamics and spatial scale in evaluating the stocks of natural resources (e.g., fish stocks), may provide significant insight into the likely future patterns of ecosystem services and changes in underlying ecosystem assets. Recent investigative research conducted by Fenichel and Abbott (2014) on the valuation of ecosystem assets has taken those ecological dynamics into account within the framework of standard capital accounting theory. Their work provides some important insights for use in the valuation of ecosystem assets within an ecosystem accounting context.

7.28. Third, a discount rate must be chosen. That is a much-discussed issue, encompassing a number of factors that need to be taken into consideration. Indeed, economists are still seeking clarity regarding what rates might be appropriate. SEEA Central Framework, annex A5.2, provides a useful summary in this regard, while at the same time highlighting the lack of such clarity in the advice proffered by experts in that area. Perhaps the key issue for ecosystem accounting is clearly articulation of the purpose of valuation and hence of the intended valuation concept. In the case in which integration with existing national accounts estimates of income and assets is required, an exchange value concept is appropriate. Consistent with this choice, the use of a market-based discount rate is in turn appropriate.

7.29. However, in the case in which a societally based valuation is required, other considerations are relevant, in particular assumptions regarding the relative social importance of various ecosystem services. There may also be interest in identifying the extent to which certain aspects of ecosystems are substitutable, for example, following Ekins (2003), who identifies some of those aspects as reflecting critical natural capital. Where preferences or desired outcomes, including taking into account the preferences of future generations, are introduced in the determination of discount rates—as distinct from the market-based approach, which is focused on expected flows—the task of selecting a discount rate likely extends beyond the remit of a national statistical office. That being said, it must be accepted that the decision to use market-based discount rates is underpinned by a set of implicit assumptions and norms.

7.30. Given the range of discount rates that may be chosen, and the impact that the choice can have on estimates of ecosystem asset value, compilers are encouraged to undertake estimation for a variety of discount rates in order to understand and demonstrate the sensitivity of the estimates.

7.31. There is an important link between the choice of approach to estimating future flows of ecosystem services and the choice of discount rate. Where it is assumed that the unit values of ecosystem services will remain constant over the life of the asset, it is necessary to use a discount rate in real terms, that is, after adjusting for inflation. Conversely, in the case in which the future path of unit values for ecosystem services is directly estimated and included in the calculations, a nominal discount rate should be used. Since the essential function of a discount rate is to reflect the time value of money, when that rate is adjusted for inflation (i.e., when it is converted to real terms), an appropriate measure of inflation is likely to be economy-wide in scope, for example, the GDP deflator.

7.32. Fourth, in the measurement of net present values, it is usual for a number of estimates of past years to be compiled at the same time to provide a time series. However, each NPV calculation for a specific time point must be based on the expectations relevant at that time point. Thus, for example, in cases in which a change in regulations is such that the use of an ecosystem asset changes, estimates of NPV before the change should be based on the earlier set of regulations and not revised based on the change in situation. The change in value associated with the change in situation (e.g., a regulation change) should be recorded as an addition or reduction in the value of ecosystem assets during the relevant accounting period.

7.3. Measuring ecosystem capacity

7.3.1. Defining ecosystem capacity

7.33. SEEA EEA describes three main ecosystem asset concepts: ecosystem extent, ecosystem condition and expected ecosystem service flows. Ecosystem capacity was recognized to be central to making the connection between ecosystem assets and ecosystem services in accounting terms, but the nature of that connection was not articulated in SEEA EEA for two reasons:

- First, it was recognized that the link between ecosystem assets and ecosystem services is hard to define and measure in ecological terms, particularly in terms of the link between changes in overall ecosystem condition and the supply of individual ecosystem services. It was deemed important to consider threshold effects, resilience, ecosystem dynamics and other non-linear factors;
- Second, since the concept of ecosystem capacity was considered to be related to the overall ecosystem asset, measuring capacity was understood to require the definition of an expected basket of ecosystem services. However, discussions on how to formulate such a definition have been inconclusive.

7.34. Since the publication of SEEA EEA in 2014, it has become increasingly apparent that the concept of ecosystem capacity is central to explaining the ecosystem accounting model and applying that model in practice. That is especially the case with respect to development of information sets that can support the discussion of sustainability. It is thus clear that further research is needed on how to capture the key aspects of ecosystem capacity and the nature of their interrelationships, together with practical examples. Utilizing recent research findings as presented in Hein and others (2016), the present section marks the beginning of a discussion on this topic.

7.35. Ecosystem capacity for accounting purposes may be defined initially as the ability of an ecosystem to generate an ecosystem service under current ecosystem conditions and uses at the maximum yield or use level that does not negatively affect the future supply of the same or other ecosystem services (Hein and others, 2016).

7.36. An extended discussion of the issues relevant to development of the definition of ecosystem capacity is provided in Hein and others (2016). The paper also examines challenges associated with applying the concept of capacity to the three main types of ecosystem services, that is, provisioning, regulating and cultural services; and provides several real-world examples of capacity assessment. Consideration of ecosystem capacity requires a joint discussion of ecosystem condition, ecosystem services and measurement, which were discussed in earlier chapters. That explains why the subject of ecosystem capacity, whose measurement is relevant in both biophysical and monetary terms, is being analysed later in the *Technical Recommendations*.

7.37. Development of the definition of ecosystem capacity has been supported by the following key insights:

(a) Capacity needs to be analysed for specific ecosystem services. The capacity of a forest to supply wood is different from its capacity to capture air pollutants or sequester carbon. The nature of capacity varies, depending on the type of services—provisioning, regulating and cultural—to which it is applied;

(b) There is a temporal dimension to the analysis of capacity. Whereas the harvest or use of provisioning services generally occurs at specific moments in time, regeneration of ecosystems is a continuous process. In other words, measures of capacity must reflect the stock of ecosystem assets and the ecosystem asset's ability to supply individual services as a flow over time. In general terms, capacity entails estimation of the sustainable use level of an ecosystem, based on whether there is sufficient regeneration of that ecosystem (growth less natural losses) to offset its use by economic units;

(c) Using one ecosystem service can reduce the ecosystem's capacity to supply other ecosystem services. For example, harvesting wood in a forest may reduce opportunities for nature-based tourism. Capacity therefore needs to be assessed in the context of the actual use of the ecosystem, for example, carbon sequestration by a forest ecosystem must be considered in the context of actual rates of timber harvesting in that forest. It is also relevant to consider competing uses of ecosystems when considering the future flows of ecosystem services;

(d) Capacity is a measure that should be related to both the supply and the use of ecosystem services. Analysing capacity requires understanding the demand for the services generated by an ecosystem asset. If there is no demand for a service, the ability of an ecosystem to generate that service is not relevant for assessing ecosystem capacity. That could be the case for, say, a flood control service provided in an area without people. Hence, a meaningful connection between capacity and sustainable use levels is conditional on there being a demand for the service involved;

(e) Generally, the application of the definition of capacity is appropriate at more aggregated scales, in particular the landscape scale and above. If capacity is assessed over too small an area, signals regarding changes in capacity may be misleading because the influence exerted by natural fluctuations or ecosystem use on the ecosystem's state will be stronger than their influence in the case of assessment of larger areas (Hein and others, 2016). For example, timber harvesting generally occurs in rotation periods; hence, the capacity to generate timber would logically be assessed for a complete forest asset rather than for individual stands.

7.38. For ecosystem accounting, capacity is related to the actual basket of ecosystem services supplied and thus requires the presence of users of ecosystem services. Capacity therefore differs from the ability of an ecosystem asset to supply ecosystem services independently from the potential use of those services by beneficiaries, which has been labelled potential ecosystem service supply (e.g., Bagstad and others, 2014; Hein and others, 2016). It could also be labelled "the capability of an ecosystem to supply services", that is, the optimal ecosystem management under which the basket of ecosystem services would be obtained (Hein and others, 2016). While both potential supply and capability are relevant concepts for ecosystem management, they would not necessarily underpin ecosystem accounting estimates, although they may be derived from a common underlying information set covering, for example, measures of extent and condition.

7.39. In cases in which there are high levels of use of the ecosystem asset (e.g., through high levels of extraction) it is expected that the actual flows of ecosystem services will be higher than the sustainable flow and hence the condition of the asset will fall. That set of circumstances would reflect ecosystem degradation.

7.40. Capacity may be monetized on the basis of the NPV of the sustainable flow of ecosystem services. A choice may need to be made when there are trade-offs between services. For example, sustainable timber logging may not be compatible with provision of maximum recreational opportunities or air filtration services by the ecosystem. For accounting purposes, the basis for this choice should be the actual or revealed patterns of use and any associated legal or institutional arrangements. Thus, if the forest is currently used primarily for timber logging, then sustainable timber logging rates should be calculated and estimates for other ecosystem services (e.g., air filtration or recreation) should be made with the same logging rates in mind, instead of there being estimates of capacity for each service based on alternative patterns of use. At the same time, greater consideration must be given to the question how that may apply in practice. One outcome, for example, may be that the unit values of ecosystem services estimated with respect to actual use are different from unit values estimated within the context of sustainable use.

7.41. Even without that consideration, it is to be noted that the NPV of ecosystem use at capacity may be lower than, higher than or equal to the NPV of actual use of the ecosystem. The selected discount rate and discounting period exert a major influence on the various valuations.

7.42. To consider capacity as being measurable in terms of individual ecosystem services is an important step forward in an accounting context, since this establishes a direct link with discussions of sustainable yield and flow, which are well established in biological models and resource economics. However, there remain significant challenges with respect to understanding the links between measures of capacity for individual services and overall ecosystem condition.

7.43. Capacity is also relevant for policymaking on ecosystems. For example, the difference between valuation of an ecosystem asset in terms of its capacity and valuation in terms of its current use provides an indication of the relative costs or benefits of unsustainable ecosystem use. Sustainable ecosystem management ultimately requires management of ecosystems at or below capacity.

7.44. Further details on analysis of capacity are provided in Hein and others (2016). Additionally, La Notte and others (2017b) have undertaken a case study on nitrogen retention services in Europe. Insights derived from recent studies such as these could serve as the basis for further discussions on how capacity may be integrated in SEEA EEA.

7.3.2. Linking ecosystem capacity and ecosystem degradation

7.45. From an accounting perspective, an important emerging dimension of ecosystem capacity measurement encompasses the link between ecosystem capacity and ecosystem degradation. In SEEA EEA (para. 4.31), ecosystem degradation is defined in relation to the decline in condition of an ecosystem asset as a result of economic and other human activity. That aligns with the approach taken in SEEA Central Framework with regard to the definition of depletion of natural resources and in the SNA with regard to the consumption of fixed capital (depreciation) of produced assets.

7.46. The emerging idea is that while ecosystem degradation is clearly related to declining condition, it can be defined more specifically as reflecting a decline in the value of an ecosystem asset as measured in relation to the change in that asset's NPV, based either on the expected flow of services, or on the ecosystem asset's capacity. In either case, only the part of the decline that can be attributed to human activity should be considered degradation, in line with the accounting definition of degradation. Note that that implies that changes in NPV due solely to changes in prices should not be considered part of degradation.

7.47. Both approaches to measuring degradation, based either on expected flows or on capacity, result in different metrics, since the NPV of expected use is different from the NPV of capacity, unless the ecosystem is used sustainably. Similarly, annual changes in the NPV of actual use and the NPV of capacity are generally different, even though the directions of change will often be related.

7.48. Within the context of that discussion, there are several approaches to measuring degradation:

(a) In physical terms, through changes in ecosystem condition indicators;

(b) In monetary terms, through changes in the NPV of the expected use of ecosystems;

(c) In monetary terms, through changes in NPV of capacity;

(d) Through changes in the NPV of the potential supply; however, this may require attributing monetary values (i.e., option values) to potential ecosystem services;

(e) In principle, through the relationship of degradation to changes in the NPV of capability, that is, of optimal use of an ecosystem, provided that such an optimal use pattern can be defined.

7.49. However, for any given ecosystem asset, there may be several ways to estimate potential supply and capability, entailing different use patterns. Thus, the last two approaches to defining degradation are unlikely to be relevant for accounting.

7.50. At present, further testing is required to assess if and when it is more appropriate to define degradation in relation to the NPV of expected use as opposed to the NPV of capacity, or whether both approaches should be considered simultaneously. It is to be noted that each approach to measuring degradation has its own specific policy-related implications: changes in the NPV of expected use reflect impacts on the economy, while changes in the NPV of capacity reflect changes in the window of opportunities for the present and future generations to manage ecosystems sustainably.

7.51. Ecosystem degradation can be examined not only in the context of the NPV of ecosystem assets but from another perspective as well: ecosystem degradation occurs when actual ecosystem service flows, in particular provisioning services, exceed the ecosystem's capacity to supply that service. Therefore, in cases in which capacity can be quantified and mapped, in particular when a fully spatial approach to ecosystem accounting is pursued, it may be used as a measure for analysing whether flows of ecosystem services in specific areas can be sustained in the future (see Schröter and others, 2014).

7.52. While ecosystem degradation may be measured most appropriately in terms either of: (a) changes in the ecosystem monetary asset account; or (b) capacity, degradation is also reflected in measures of changes in ecosystem condition and, depending on how the ecosystem is used, in flows of ecosystem services, since the expected flows ultimately decrease over time as a result of ecosystem degradation. As research on degradation advances, it is important to ensure coherence of approaches across the various components of ecosystem accounting.

7.53. There have been proposals for the development of accounts for ecosystem capacity. At that stage, however, an ecosystem capacity account has not been defined. Instead, emphasis is being placed on the measurement of ecosystem capacity for individual services to enable a more complete understanding of the extent to which current patterns of use differ from patterns of use that would leave the condition of the ecosystem asset unchanged. In principle, an ecosystem capacity account could be compiled in the same format as the ecosystem monetary asset account based on individual services (see table 7.2), with the difference being that the values recorded would reflect NPV at sustainable use rather than at actual use.

7.54. From an ecosystem accounts compilation perspective, the need for further discussion on ecosystem capacity in no way limits the potential for compiling most other ecosystem accounts. Indeed, the compilation of the various accounts (extent, condition, ecosystem services supply and use) are important in providing the measurement experience and detail for the refinement of the measures of ecosystem capacity that have been discussed.

7.4. Recording ecosystem degradation

7.4.1. Accounting entries for degradation and depletion

7.55. From a national accounting perspective, the concept of ecosystem degradation has a specific import. It encompasses the capital cost that should be deducted from the gross income arising from the use of an ecosystem asset in production. Thus, degradation should not include changes in the value of the asset that occur for other reasons. In particular, reductions in asset value due to unforeseen events that are not related to the use of the asset in production (e.g., natural disasters) are not considered part of degradation for accounting purposes. Those reductions—which are treated as a distinct entry, "Other changes in volume"—contribute to an understanding of the overall change in the value of assets over an accounting period. Further, changes in the value of an asset may be due solely to changes in prices, in which case they are considered revaluations for accounting purposes and separately recorded.

7.56. Those distinctions between accounting entries are reflected in table 7.3, where the series of entries between opening and closing stock are characterized for various types of assets. It is to be noted that for ecosystem assets, depletion constitutes a subset of degradation, since depletion refers only to the capital cost associated with provisioning services from an ecosystem, in cases where the provisioning services are being generated unsustainably. Degradation encompasses capital costs associated with provisioning and other ecosystem services. An important requirement is that the table exhibit a consistency of treatment within the accounting framework with respect to consumption of fixed capital (depreciation of produced assets), depletion and degradation.

Table 7.3
Accounting entries for depletion and degradation

Types of assets	Accounting entry				
	Opening stock	*Transactions*	*Other changes in volume*	*Revaluations*	*Closing stock*
Produced assets		Gross fixed capital formation (investment) **Depreciation**	Primarily physical appearance and disappearance of assets - Discoveries - Catastrophic losses - Reappraisals of stock	Changes in value between opening and closing stocks due solely to changes in prices of assets	
Natural resources		**Depletion**			
Ecosystem assets		**Degradation**			

7.57. However, within this accounting construct, further consideration is required of exactly how ecosystem degradation should be defined, building on the discussion in the previous section on the measurement of ecosystem capacity and on some additional factors (SEEA EEA, chap. IV), namely:

- Treatment of complete changes (conversions) in the use of an ecosystem asset, for example, from a forest area to an agricultural area;
- Treatment of situations in which economic activity, including household consumption, has indirect and potentially delayed impacts on ecosystem condition, for example, impacts arising from human-induced climate change;
- Treatment of declines in condition of ecosystems that are not direct suppliers of final ecosystem services, for example, remote forests.

7.4.2. Allocation of ecosystem degradation to economic units

7.58. Allocation of ecosystem degradation represents one of the longest-standing challenges to the development of fully integrated environmental-economic accounts. SEEA Central Framework proposes a treatment through which the depletion of natural resources can be incorporated within the standard sequence of accounts of the SNA. That treatment recognizes that the "using up" of natural resources is a capital cost against the future income of the extractor, and one that should be attributed to the extractor.

7.59. A number of alternative approaches to the allocation of degradation have been suggested. What is perhaps the most obvious approach entails attribution of degradation to the economic unit that caused the degradation, assuming that this can be determined. Determining the relevant economic unit may be difficult owing to the factors of distance, that is, when impacts are felt in neighbouring ecosystems, and time, that is, when the impacts become evident after the activity occurred. As a result of either of these factors, the relevant economic unit, that is, the unit that should be presented as bearing the capital cost, may not be the manager or owner of the particular ecosystem asset suffering the degradation. Further, attributing the overall impacts may be a complex issue, since the physical degradation of an ecosystem is likely to exert an impact on the supply of multiple ecosystem services that are received by different users.

7.60. The estimation of depreciation (or consumption of fixed capital) for produced assets entails a different approach that does not involve such factors. Depreciation can be attributed directly, since there is only one owner/user who receives all of the benefits/services of the asset in the generation of output and income. Thus, while the national accounting framing of ecosystem assets and the conceptualization of degradation are clear, there still remain practical measurement challenges, including related choices, which require further discussion and research.

7.4.3. Use of the restoration cost approach to valuing ecosystem degradation

7.61. A commonly discussed alternative approach to valuing ecosystem degradation—that is, other than in relation to the change in the NPV of ecosystem assets—entails the use of estimated restoration (and maintenance) costs. Such an approach was initially suggested in the original SEEA (United Nations, 1993). Under that approach, an estimate is made of the expenditures that would be required (i.e., not actual expenditures) to restore an ecosystem to its condition at the beginning of the accounting period. That line of thinking is sometimes extended to include the notion that the accumulated unpaid restoration costs represent a liability—an ecological debt (Weber, 2011). It is assumed that if the estimated restoration costs were in fact made, then there would be no recorded decline in condition, that is, there would be no degradation.

7.62. In the environmental-economic community (e.g., Barbier, 2013), restoration cost approaches are not the approaches of choice since: (a) they do not reflect the change in the value of the associated services resulting from the loss of condition; and (b) the restoration costs are not revealed (i.e., actually paid) costs. In recent work on the subject (Obst and Vardon, 2014; Obst, Hein and Edens, 2016), it has been observed that, in accounting terms, restoration costs are not equivalent to those associated with estimating depreciation, or with consumption of fixed capital. That is, in the estimation of consumption of fixed capital, the terms "replacement cost" and "restoration cost" refer to the expenditure required to replace an asset in its depreciated condition, not to return it to an "as new" condition. Finally, it is also to be noted that the extension of the accounting framework to integrate the value of ecosystem services allows a different perspective on degradation to be supported within that framework.

7.63. An alternative approach to the use of estimated restoration costs in the valuation of ecosystem degradation might involve examining whether, between the beginning and end of an accounting period, there has been a significant change in the estimated restoration costs. Thus, a rise in the estimated restoration costs in real terms might be an indicator of the cost of a decline in condition between those two points in time. Another approach might entail considering not the cost of restoring an ecosystem to an earlier condition but rather the cost, including time, of "building" the ecosystem, starting from a zero base, up to its currently observed condition. That could be considered equivalent conceptually to the replacement cost approach within the context of measuring consumption of fixed capital. The change in total restoration cost between two points in time might be an alternative measure of the valuation of degradation.

7.64. The general conceptual issue here is whether, for a basket of ecosystem services from a given ecosystem asset, the estimated restoration costs can be related to a least cost (purchase price) for the supply of that basket of services and hence provide an estimated value of the ecosystem services for accounting purposes. The underlying logic is akin to that of the standard approach in national accounts for the estimation of government services such as health and education, which are measured at cost. While that conceptual issue is somewhat different from the challenge of measuring ecosystem degradation, it is not unrelated. In any case, it is clear that further discussion on the appropriate accounting interpretation of estimated restoration costs is required.

7.65. Notwithstanding the issues surrounding the use of restoration cost approaches for the valuation of degradation, the estimation of potential restoration costs can provide valuable information for policy purposes. For example, estimation of costs can provide a discussion of ecosystem degradation with a sense of economic scale, especially where that discussion revolves around the issue of the resources required to maintain condition, that is, where government establishes upfront charges or bonds in relation to business use of ecosystem assets or associated spatial areas such as mining sites. It may also be useful from an analytical perspective to compare the estimated restoration costs with the actual expenditures on ecosystem maintenance. When those costs and expenditures are tracked against actual changes in ecosystem condition, it is likely that some useful information for policy purposes will emerge.

7.5. Recommendations for compiling an ecosystem monetary asset account

7.66. To date, there have been only a few examples of the development of ecosystem monetary asset accounts. The results of one such undertaking—a pilot-testing of the ecosystem monetary asset account conducted in Southern Palawan (Philippines)—are presented in a World Bank technical report (WAVES, 2016). As the acquisition of further experience with regard to these accounts is still required, recommendations on their compilation should be viewed as preliminary.

7.67. In principle, the ecosystem monetary asset account should reflect all final ecosystem services supplied by the ecosystem assets in the ecosystem accounting area. In practice, however, a selection is often made based on policy priorities and data availability. The user of the account should be informed of the basis for the selection, and the consequences in terms of the values analysed should be clearly described. In section 3.5 of SEEA EEA, advice is provided on relevant criteria for selecting ecosystem services for measurement.

7.68. Estimation of ecosystem asset values entails crucial assumptions pertaining to the selection of the discount rate and the asset life, as well as assumptions regarding use patterns of ecosystems, which should reflect current uses, unless there are clear indications of forthcoming changes in use patterns. Selection of the discount rate and the asset life should be guided by the principle that where the purpose is to integrate or compare asset values with those obtained from the SNA, for example, in compiling national wealth accounts, the compiler of the ecosystem accounts should seek an alignment with assumptions made in the national accounts.

7.6. Key research issues

7.69. Overall, it is further piloting and testing of the compilation of ecosystem monetary asset accounts and ecosystem capacity that constitute the important requirement in this area. Specific research efforts within the framework of these activities should include:

- Establishing principles for estimating future expected and sustainable use patterns of ecosystem services and associated deliberative scenario approaches;
- Analysing whether a social discount rate may be appropriate for public-good ecosystem services;
- Testing whether constant unit values for ecosystem services can be assumed in the calculation of NPVs and if so, in what manner and when;
- Testing the analysis of capacity for various ecosystem types in different social and environmental contexts, (see Hein and others (2016) for a first set of examples);
- Testing how ecosystem asset values and ecosystem capacity can be linked to degradation and depletion and how in practice degradation and depletion due to human actions can be separated from impacts of natural disturbances;
- Testing policy applications of ecosystem asset values and capacity accounts.

7.70. Given that a definition of ecosystem capacity is still emerging, it is recommended that the measurement of ecosystem capacity be regarded as a very high-priority topic of ongoing research. The principal aims in the short term should be: (a) to reach a common understanding of the definition of ecosystem capacity and its relationship to other, similar concepts; and (b) to articulate the role of ecosystem capacity within the accounting system with respect primarily to defining ecosystem degradation.

7.71. It would be beneficial for countries and agencies that undertake testing of ecosystem accounting to consider—as a means of supporting research on ecosystem capacity—questions related to the links between flows of ecosystem services and measures of ecosystem condition. Those links should, in any event, be a focus of testing, since it is generally accepted that the measurement of condition must integrate information on the management and use of ecosystems, and that modelling the flows of ecosystem services, particularly regulating services, include the use of information on ecosystem condition.

Chapter VIII
Integrating ecosystem accounting information with standard national accounts

Key points

- Full integration of ecosystem accounting information with standard national accounts—through integration of information on ecosystem extent, ecosystem condition and ecosystem services in physical and monetary terms—entails several steps. From a national accounting perspective, such integration may be considered the end point of measurement.
- There are four broad types of integration: combined presentations, extended supply and use accounts, institutional sector accounts and balance sheets. Each type provides information designed to address specific policy and analytical issues.
- Combined presentations bring together information on ecosystems and the economy without requiring the estimation of ecosystem services and assets in monetary terms. For example, information on physical flows of ecosystem services to agriculture can be compared with estimates of agricultural value added and employment from the national accounts.
- Extended supply and use accounts support the analysis of extended supply chains and the integration of ecosystem services to create extended economic production functions.
- Institutional sector accounts provide the means by which standard aggregates of income and production can be adjusted for ecosystem degradation, that is, the cost of using up ecosystem capital.
- Balance sheets provide the framework for extended measures of wealth, incorporating the value of a complete range of ecosystem services embodied in ecosystem assets. Standard economic accounts, on the other hand, incorporate values related only to provisioning services.
- In contrast with combined presentations, the other types of integration require ecosystem data to be estimated in monetary terms. Thus, the measurement challenges outlined in chapters VI and VII apply, especially regarding the application of net present value techniques to the measurement of both ecosystem assets and ecosystem degradation.
- There are other approaches to the integration of ecosystem and economic data, including wealth accounting and full cost accounting. While they have a goal similar to that of SEEA-based approaches, some of the measurement concepts and boundaries they apply are different.

8.1. Introduction

8.1. The integration of ecosystem accounting information with standard economic data is an important component of work within the context of SEEA. That indicates that this system has been developed to extend and complement the standard economic accounts of the SNA. Indeed, the prime aim of some in developing SEEA has been to derive adjusted measures of national income and economic activity, which take into account environmental information in the form, for example, of depletion- or degradation-adjusted measures of GDP.

8.2. What emerges from the development and testing of SEEA EEA is the awareness that calculating adjustments to national income and national wealth for ecosystem degradation and ecosystem enhancement cannot be regarded as a straightforward or direct process. Indeed, in recent years, what has also emerged is a recognition of the need to consider a series of issues outlined in SEEA EEA and in the *Technical Recommendations*, namely, spatial units, scaling and aggregation, ecosystem services, ecosystem condition, ecosystem capacity and ecosystem valuation.

8.3. Hence, while a theoretical framework for integrated accounting of ecosystems and economic activity is largely in place, its implementation not only constitutes the end point of a series of compilation steps (described in sect. 8.2) but also requires a range of assumptions on the nature of the required valuation and integration. Compilers should recognize that some of those accounting matters remain the subject of ongoing discussion.

8.4. The achievement of a full integration of ecosystem accounting information remains an ambitious goal. At the same time, it is important to recognize that there are various means by which ecosystem accounting data can be combined with economic data. Section 8.3 examines combined presentations whose use is valuable in this context.

8.5. The present chapter, which builds on the discussion presented in SEEA EEA, chapter VI, summarizes some key points to be considered within the context of integrating ecosystem accounting data with standard economic data.

8.2. Steps for full integration with national accounts

8.6. Historically, the approaches to integrating ecosystem-related information with the national accounts have directly associated themselves with the issue of valuation of degradation and the appropriate recording and allocation of degradation in the accounts. That is characteristic of the different approaches outlined by national accountants (e.g., Harrison, 1993; Vanoli, 1995). However, the question of how exactly the integration should be undertaken has never been fully resolved.

8.7. Significantly, as explained in both SEEA EEA and other literature (e.g., Edens and Hein, 2013; Obst, Hein and Edens, 2016), the emergence of the concept of ecosystem services has enabled a reconceptualization of integration with the national accounts. That new basis for integration, which serves as an underpinning of SEEA EEA, is discussed here.

8.8. Generalized steps towards full integration may be derived through utilization of the concept of ecosystem services. The precise ordering of those steps varies in practice, and iteration between steps is to be expected. It should be noted that where the intention of an ecosystem accounting project is to focus primarily on the measurement of the value of ecosystem assets, commencement at step five and incorporation of information from earlier steps only as required may be the most appropriate approach. The steps are the following:

(1) Delineate the relevant spatial areas to create mutually exclusive ecosystem assets;

(2) Identify and measure the supply of ecosystem services from each ecosystem type or asset and determine the relevant users;

(3) Measure the condition of each ecosystem asset;

(4) Assess the future flows of ecosystem services from each ecosystem asset based on consideration of the current condition and capacity of ecosystem assets;

(5) Estimate the monetary value of all ecosystem services;

(6) Estimate the net present value of the future flows of each ecosystem service and aggregate to provide a point-in-time estimate of the monetary value of each ecosystem asset;

(7) Estimate the change in net present value over an accounting period and determine the monetary value of ecosystem degradation;

(8) Integrate values of the production and consumption of ecosystem services, the value of ecosystem degradation and the value of ecosystem assets into the standard economic accounts.

8.9. It is clear from that list of steps, which is itself somewhat stylized, that the full integration of ecosystem accounting information into the standard national accounts (step 8) is not a straightforward process. At the same time, maintaining a longer-term objective of integration provides a clear purpose and rationale for the selection and structuring of the ecosystem information that is required in the previous steps. Further, the information organized to enable the previous steps to be carried out is highly useful in its own right for decision-making and monitoring. Consequently, while achieving the objective of full integration may be challenging, that objective plays an important part in providing ecosystem accounting with a direct focus.

8.10. Working through the steps requires aggregation across ecosystem services and ecosystem assets, which is a significant challenge. For aggregation, a range of assumptions must be made regarding the relationships between various ecosystem services and ecosystem assets. There is often an implicit assumption, in particular, that separate estimates for different services and assets can be summed. The reality, however, is that such a summation tends to abstract, to some degree, from the inherent complexity of the underlying ecosystem functions and processes in the same way, the national accounts abstract from the underlying intricacies of the economic system. The question for compilers and analysts is whether the degree of abstraction that characterizes ecosystem accounts is appropriate for better-informed decision-making on the use and management of ecosystems.

8.3. Combined presentations

8.11. Combining the information from ecosystem accounting with that in the standard national accounts can be carried out directly through the use of combined presentations (see SEEA Central Framework, chap. VI). In essence, such presentations are tables that support the presentation of information from a variety of sources in a manner that facilitates comparison of economic and environmental data. That is achieved through the use of common classifications and accounting principles.

8.12. Two types of combined presentations within the context of ecosystem accounting are: (a) the combination of information for specific ecosystem assets on changes in condition with information on the expenditure on environmental protection of those assets; and (b) the combination of information on the flows of ecosystem services generated by an ecosystem asset with information on the economic activity associated with that asset. Concrete examples of the second type are presentation of data on flows of ecosystem services from a forest alongside data on employment in the forestry industry and comparison of agriculture-related ecosystem services with agricultural value added. Such comparisons may provide insight into the relative significance of ecosystem service flows for various beneficiaries.

8.13. Data on potential restoration costs and actual expenditures on the maintenance and restoration of ecosystem assets are another type of information for inclusion in combined presentations that may support decision-making. Information on restoration costs is likely to be of particular relevance in the management of ecosystems and in determining the level of investment in ecosystems that may be needed to maintain or improve condition.

8.14. Over time, information gathered on the actual expenditure on restoring ecosystem assets may be complemented by information on flows of ecosystem services, through which a more complete picture of the relationships between ecosystem condition and ecosystem services could emerge. Indeed, one of the key roles of the ecosystem accounting model is to facilitate the organization of these types of information and thereby furnish support for more detailed analyses in the future.

8.15. SEEA EEA (chap. VI), provides additional commentary on combined presentations. The key point is that there is room for considerable flexibility in the design of combined presentations. While they do not encompass a full integration of information in accounting terms, they could buttress a more informed discussion of the relationship between ecosystems and economic activity in a manner that takes into account spatial and environmental contexts. Further, they may help support the presentation of indicators for monitoring trends in ecosystem-related outcomes.

8.4. Extended supply and use accounts

8.16. Extended supply and use accounts represent the first accounts where explicit consideration must be given to the boundaries between current economic measures and measures of ecosystem services in terms of the structure of the accounts. The striving in the augmented supply and use accounts is to present the information on the supply and use of ecosystem services as extensions to the standard SNA supply and use accounts.

8.17. Building on the discussion in chapter V concerning ecosystem services supply and use accounts, as reflected in table 5.1, there are two key aspects of that extension. First, given that the ecosystem accounting model implies an extension to the standard production boundary, the set of products within scope of the supply and use accounts becomes broader, and hence the size of the supply and use accounts must increase. That can be carried out through the addition of new rows representing ecosystem services.

8.18. The requirement here is to ensure that those ecosystem services are distinguished clearly from the products (SNA benefits) that are already within the standard supply and use accounts. For the relevant products, final ecosystem services represent the intermediate consumption of the producers. For example, the ecosystem service of accumulation of pasture for livestock represents the intermediate consumption of producers raising livestock. For ecosystem services that contribute to non-SNA benefits, additional rows for both the ecosystem services and the new benefits need to be incorporated.

8.19. Conceptually, it is possible to further extend the supply and use accounts so that it can also incorporate intermediate ecosystem services. For example, where pollination services are of relevance, an additional row might be added as a means of recognizing those flows as inputs to the generation of final ecosystem services. However, the general recommendation is that the extension of supply and use accounts should be limited to final ecosystem services. This reflects the belief that: (a) if intermediate services were added to the supply and use accounts, then there would be an increase in the complexity of the table; and (b) from an economy-wide production perspective, any recorded intermediate services would net out in accounting terms, and their effect would be embodied in the final ecosystem services. Intermediate services, and hence of flows between ecosystems, may be better analysed using data from the basic ecosystem services supply and use accounts found in chapter V.

8.20. The second key aspect of the extension of the supply and use accounts entails the requirement that columns be added to take into account the production of ecosystem services, that is, that ecosystem assets are to be considered additional producing units alongside the current set of establishments classified by industry (agriculture, manufacturing, etc.). Given that supply and use accounts are generally compiled at the national level, it may be sufficient to introduce simply one additional column to cover the production of all ecosystem services by all ecosystem types. In that case, the level of detail would be reflected in the ecosystem services supply and use account. However, there may be interest in adding columns for certain ETs (ensuring aggregation to national level) or for specific EAAs within a country (e.g., specific water catchments, protected areas or subnational jurisdictions).

8.21. Environmentally extended input-output tables (EE-IOT) represent a related extension. These tables are regularly compiled, including at regional and world levels, both for the analysis of embodied greenhouse gas emissions, water and similar environmental flows and to support analysis of interlinkages and spillover effects of policies and shocks to the economic system. An introduction to EE-IOT is contained in *System of Environmental-Economic Accounting 2012—Applications and Extensions*, chapter III (United Nations, European Commission, FAO, OECD and World Bank Group, 2017).

8.22. For EE-IOT, information on environmental flows (e.g., greenhouse gas emissions by industry) is appended to the standard input-output table, with matrix algebra then being used to integrate the data for analytical purposes. What is required is that the information on environmental flows be classified and structured in the same manner as standard input-output data. The additional information may be provided in either physical or monetary form. The standard input-output data, on the other hand, remain in monetary form. Thus, using EE-IOT techniques, it is possible to analyse selected ecosystem services without developing a fully extended supply and use accounts.

8.23. However, for EE-IOT, it is not necessary to make any changes to the standard SNA production boundary. The extended supply and use accounts envisioned here is based on the full integration of ecosystem services with the standard supply and use accounts through the use of an extended production boundary relative to the standard supply and use accounts. That is a significant development.

8.24. An important result of integrating the flows of ecosystem services in the extended supply and use accounts is that it becomes clear how the commonly discussed topic of double-counting can be managed. Quite commonly, there is concern that integrating ecosystem services with the national accounts will result in double-counting in terms of impacts on GDP if the final ecosystem services that contribute to SNA benefits are included. The stylized presentation in table 8.1 demonstrates that double-counting can be avoided, provided that the series of entries, from production through to final use via the supply chain, are recorded appropriately. The gross basis of recording that is used in table 8.1 is by far the most transparent means of dealing with double-counting for accounting purposes.

Table 8.1
Integration of final ecosystem services with current national accounts estimates (example)

	Ecosystem asset (forest)	Forestry industry	Manufacturing industry	Households final demand	Total
PART A					
Supply					
- Logged timber		50			50
- Furniture			80		80
Use					
- Logged timber			50		50
- Furniture				80	80
Value added (supply less use)		50	30		80
PART B					
Supply					
- Ecosystem service–growth in timber	30				30
- Logged timber		50			50
- Furniture			80		80
Use					
- Ecosystem service–growth in timber		30			30
- Logged timber			50		50
- Furniture				80	80
Value added (supply less use)	30	20	30		80
PART C					
Supply					
- Ecosystem service–growth in timber	30				30
- Ecosystem service–air filtration	15				15
- Logged timber		50			50
- Furniture			80		80
Use					
- Ecosystem service–growth in timber		30			30
- Ecosystem service–air filtration				15	15
- Logged timber			50		50
- Furniture				80	80
Value added (supply less use)	45	20	30		95

Source: Obst, Hein and Edens (2016).

8.25. Table 8.1 is a stylized supply and use account relating to timber production. It is divided into three parts. Part A presents the standard recording of timber production for furniture purchased by households, that is, no ecosystem services are recorded. The stylized recording presented here ignores all other inputs and potentially relevant flows (e.g., labour costs, retail margins).

8.26. Part B extends that recording to include the flow of the provisioning service of timber from the ecosystem asset (a forest) to the forestry industry. The main effect is to partition the value added of the forestry industry between the industry and the ecosystem asset. It should be noted that, while the total supply has increased owing to the inclusion of the production of ecosystem services, the overall value added remains unchanged (at 80 currency units). That reflects the increase in the production boundary and demonstrates how the accounting framework deals with the challenge of double-counting.

8.27. Part C introduces a second ecosystem service, air filtration, which is supplied by the ecosystem asset. Again, total production is further increased, but in this case, value added also rises because the additional production is not an input to existing products, that is, SNA benefits. The increase in value added from production is also reflected in increased final demand of households.

8.5. Integrated sequence of institutional sector accounts

8.28. As discussed, for certain purposes, it may be relevant to integrate ecosystem information into the broader sequence of institutional sector accounts and balance sheets of the SNA. The general underpinning logic and the structure of the sequence of accounts is described in detail in the SNA and is summarized in SEEA Central Framework, chapter VI. The informational focus in these accounts shifts from production and consumption towards the institutional sector level (i.e., corporations, governments, households) and measures of income, saving, investment and wealth.

8.29. One of the main functions of the sequence of accounts is to demonstrate the linkages among incomes, investment and balance sheets. In that regard, a key feature of the standard SNA sequence of accounts is the attribution of consumption of fixed capital (depreciation) to economic activities and institutional sectors as a cost against income.

8.30. The type of presentation that emerges from such integration is shown in table 8.2, which is taken directly from SEEA EEA, annex A6. Table 8.2 presents two models (A and B) for a simplified example. In the example, presented for a farm, a single ecosystem asset provides a mix of ecosystem services (total of 110), of which 80 are used by the farmer and 30 are final consumption of households. The allocation is based on the assumed composition of the ecosystem services. Thus, the value of 80 for ecosystem services may be considered inputs to agricultural production and the value of 30 may be considered regulating services, such as air filtration, used by households.

8.31. All SNA production of the farmer (200) is recorded as final consumption of households. For simplicity, no other production, intermediate consumption or final consumption is recorded. It is to be noted that in the generation of ecosystem services, table 8.2 does not show any "inputs" from the ecosystem (i.e., intermediate ecosystem services). Recording these flows is not required for the purposes of developing a sequence of accounts focused on economic units.

8.32. As shown in table 8.1, the rise in gross value added (GVA) occurs only in relation to the final consumption of ecosystem services that are related to non-SNA benefits (the air filtration services of 15 units in that table). In the following example, shown in table 8.2, final consumption of 30 units is attributed to households and contributes to a final measure of GVA of 230 units. In model A, GVA is allocated between the value added of the farmer (120 units) and the value added of the ecosystem asset (110 units). In model B, all of the value added is attributed to the farmer based on the assumption that it is the economic unit that manages the ecosystem asset and hence the generation of ecosystem services.

8.33. Having derived extended measures of GVA, these measures can now be adjusted for the cost of capital in the derivation of that GVA. This includes the deduction of depreciation of produced assets (consumption of fixed capital), depletion of natural resources and ecosystem degradation. In the SNA, only depreciation is deducted to provide a measurement of net value added (NVA). Deduction of all costs of capital provides a measure referred to as degradation-adjusted NVA. In table 8.2, total depreciation is 10 units, and ecosystem degradation is 15 units.

Table 8.2
Simplified sequence of accounts for ecosystem accounting

	Model A				Model B		
	Farmer	Household	Ecosystem	Total	Farmer	Household	Total
Production and generation of income accounts							
Output–products	200			200	200		200
Output–ecosystem services			110	110	30		30
Total output	200		110	310	230		230
Intermediate consumption–products	0		0	0	0		0
Intermediate consumption–ecosystem services	80		0	80	0		0
Gross value added	120		110	230	230		230
Less consumption of fixed capital (SNA)	10			10	10		10
Less ecosystem degradation (non-SNA)			15	15	15		15
Degradation-adjusted net value added	**110**		**95**	**205**	**205**		**205**
Less compensation of employees–SNA	50			50	50		50
Degradation-adjusted net operating surplus	60		95	155	155		155
Allocation and use of income accounts							
Degradation-adjusted net operating surplus	60		95	155	155		155
Compensation of employees		50		50		50	50
Ecosystem transfers	80	30	-110	0	-30	30	0
Disposable income	140	80	-15	205	125	80	205
Less final consumption–products		200		200		200	200
Final consumption–ecosystem services		30		30		30	30
Degradation-adjusted net saving	**140**	**-150**	**-15**	**-25**	**125**	**-150**	**-25**

Source: SEEA EEA (2014), annex A6, table A6.1.

8.34. At an economy-wide level, the resulting measure of degradation-adjusted net value added (205 units)—assuming no cross-border flows in relation to ecosystem services—are the same irrespective of the choice of model A or B. However, when compiling institutional sector accounts in the case in which the economy-wide results are allocated between, for example, corporations, governments and household sectors, in order to move forward, a choice is required regarding whether ecosystems should be treated as: (a) producing units in their own right (model A); or (b) assets owned and managed by existing economic units (model B).

8.35. In the *Technical Recommendations*, no explicit recommendation regarding model A versus model B is provided. However, discussions on other ecosystem accounting-related issues, particularly recording of the supply of ecosystem services, suggests that treatment of ecosystem assets as distinct producing units accords neatly with the measurement logic applied in other parts of the ecosystem accounting framework.

8.36. The significant implication of recognizing ecosystem assets as constituting a distinct sector is that all ecosystem degradation are deducted from the value of the ecosystem services generated by those assets. That is to say, the degradation is allocated to the ecosystem assets as the producing units in the model. Thus, in table 8.2 under model A, degradation-adjusted net value added for ecosystems is 95 units.

8.37. That issue is resolved, at least in principle, in model B, since it does not introduce an additional sector for ecosystem assets but, instead, allocates each ecosystem asset to a specific institutional sector. The cost of capital for each ecosystem asset owned and managed by each sector is then directly attributed in the accounting structure. Thus, ecosystem degradation of 15 units is allocated to the farmer, whose adjusted net value added is recorded as 205 units.

8.38. The challenge presented by application of model B in practice is related to the extent to which individual ecosystem assets can be attributed to individual economic units and sectors. While this may be clear-cut in those cases in which a unit is a direct user of specific ecosystem services, in cases where the supply of public services (e.g., water regulation) comes from private landholdings, complete allocation of an asset and its value to a single institutional sector may not be appropriate.

8.39. In this example, within the context of a full accounting system approach, allocating all of the ecosystem asset to the farmer could imply that the ecosystem asset's full value to the farmer should be recorded on the farmer's balance sheet, including both the ecosystem services used as input to farm production and the publicly consumed air filtration services. However, that may not provide a suitable recording on the balance sheet of the allocation of assets.

8.40. The issue to be resolved is that of the balance between the allocation of the costs of degradation to an appropriate economic unit and the attribution of the ecosystem assets' value to the economic unit to the appropriate user of the services. The same accounting challenge was confronted with respect to the allocation of depletion of mineral and energy resources in SEEA Central Framework. The resolution in that case entailed showing a series of transfers whereby the depletion cost was attributed to the unit extracting the resources and the balance sheets reflected the future income streams attributable to two sectors, the mining and general government units. Similar transfers could be envisaged for ecosystem accounting purposes, but such recording has not yet been developed.

8.41. It is to be noted that the approach to the allocation of degradation may in some cases be relatively straightforward. However, in many other cases the impacts of economic activity on the environment are of a complex nature. For example, the impacts may be experienced well away from their source or well after they arose, or they may not be felt by the relevant units. In addition, it is not necessarily clear how the loss of benefits incurred by the impacted sectors should be related to the income of the sector exerting the impact. Those matters have been debated at length in the national accounting community without any clear resolution. Thus, while an appropriate accounting treatment may be determined, the application of the treatment in practice and recommendations on a preferred approach requires further discussion of that treatment over a range of cases in which economic and human activity leads to degradation of ecosystem assets.

8.42. The final section of table 8.2 presents the allocation and use of income accounts. The aim of those accounts is to provide a measure of saving for the economy as a whole and for each sector. Under model A, that requires recording an adjustment entitled "ecosystem transfers", which reflects the need of the farmer and household sector for resources with which to purchase ecosystem services from the ecosystem assets.

Recording those transfers enables the saving of the three sectors in model A to reflect the actual cash positions, which, it is to be recognized, are not affected by flows of depreciation or degradation.

8.43. Under model B, ecosystem transfers are not required, since there is no stand-alone ecosystem sector. The difference between net saving for farmers under model A and net saving under model B reflects the simple allocation in model B of ecosystem degradation (15 units) to the farmer, thus reducing the farmer's net saving from 140 to 125 units.

8.6. Extended and integrated balance sheets

8.44. On balance sheets, which are the second type of integrated accounts, the opening and closing values of ecosystem assets in monetary terms, as recorded in the ecosystem monetary asset account, are integrated with the values of asset and liabilities recorded on the standard balance sheet of the SNA. Such an integration would lead to the derivation of extended measures of national and sector net wealth.

8.45. The integration of ecosystem asset values may appear to constitute a relatively straightforward step. However, it is likely, for a variety of reasons, to exhibit a high degree of complexity, entailing two main challenges, which are described at greater length in SEEA EEA, chapter VI. First, in a full SNA and SEEA Central Framework balance sheet, there are already values recorded for natural resources, such as timber and fish. Since the value of these resources is embedded in the value of ecosystem assets, through the valuation of provisioning services, it is necessary to ensure appropriately that the value of natural resources is not double-counted. That issue pertains to various cultivated biological resources, such as orchards and vineyards.

8.46. Second, in many countries, the value of land, as recorded on the SNA balance sheet, is estimated in terms of its market price. Since there is a generally well-established market in land, balance-sheet values may be obtained more directly than by using net present value techniques as applied in resource accounting. It is likely to be the case that the market values of land, particularly agricultural land, will capture the value of some ecosystem services, at least to a certain extent. However, they are unlikely to capture a full basket of ecosystem services, particularly those that have clear-cut public-good characteristics and longer-term benefits. Also, land value may well reflect dimensions that are not of an ecosystem services character—for example, the location and the value of alternative uses (e.g., urban development). Adjusting market values of land based on these considerations therefore requires careful consideration.

8.47. Recognition of the differences in underlying scope among environmental assets is important when comparing the values of ecosystem assets with values currently incorporated in SNA balance sheets. In broad terms, the SNA balance sheets have lower values for environmental assets as a result of the inclusion by SEEA EEA of the values of additional ecosystem services. At the same time, SEEA EEA values of ecosystem assets do not cover all environmental assets, most notably subsoil mineral and energy resources.[48] The effects of those two types of differences on the total value of environmental assets vary from country to country.

8.48. Integration of the accounts poses a final challenge, which arises when the accounting approach is applied at the level of an individual ecosystem asset. It should be recalled that the valuation of an ecosystem asset is directly related to the basket of final ecosystem services that are expected to be generated from that asset. At the level of individual ecosystem assets, however, there are cases in which an asset supplies few, or no, final ecosystem services (e.g., a forest on a high mountain) but, instead, plays

48 Accounting for these environmental assets is described in the SEEA Central Framework.

a supporting role in supplying intermediate services to neighbouring ecosystems. In that situation, an ecosystem asset may be recorded as having zero monetary value, and its value becomes embodied in the value of the neighbouring ecosystems. While at an aggregate national level that may not be a significant issue, it is likely to be of concern if attribution of value is being examined, or accounting is being undertaken, at smaller subnational scales. Resolution of the issue requires the incorporation of intermediate services into the ecosystem accounting model in an explicit manner and related work on recording dependencies between ecosystem assets.

8.49. From a national accounting perspective, the development of a sequence of accounts and balance sheets represents an important objective that helps motivate the development of other parts of the ecosystem accounting framework. At the same time, it is clear: (a) that work is needed to ensure progress in the development of the ecosystem accounts that must underpin the integrated accounts described here; and (b) that further research and testing are needed to meet the challenges posed by integration. Consequently, it is recommended that countries focus their efforts on developing ecosystem extent and condition accounts and ecosystem services supply and use accounts, which possess tremendous value in their own right.

8.7. Alternative approaches to integration

8.50. The preceding sections describe integration as achieved through institutional sector accounts and balance sheets, following standard SNA measurement definitions and boundaries. That is a logical approach for SEEA and is important when data already published in the national accounts—for example, on national wealth and saving—are to serve as the starting point for extension using ecosystem accounting data. However, there are other integrated measurement approaches that do not apply SNA standard measurement definitions and boundaries and hence offer alternatives to the integration of ecosystem and economic data. Three such alternative integrated approaches are summarized below (see paras. 8.51 to 8.60).

8.51. A well-developed approach, usually referred to as wealth accounting, has been developing as a branch of economics since the mid-1970s. Wealth accounting seeks to aggregate the value of all relevant capitals, including produced, natural, human and social capital. The most prominent work in this regard has been accomplished by the World Bank (2011), and UNU-IHDP and UNEP (2015). While varying in their details, those methods are nonetheless broadly similar in their approach.

8.52. In concept, wealth accounting aims at valuing each form of capital in terms of its marginal contribution to human welfare (Dasgupta, 2009; Arrow and others, 2012). Achieving that aim entails estimation of shadow prices for each type of capital. From a national accounting perspective, the focus on marginal contributions is appropriate. However, the national accounts focus on estimating contributions to market-based income, which requires the estimation of exchange values rather than shadow prices.

8.53. Given the purpose of wealth accounting, the conceptual basis for the approach to integration is highly appropriate. However, in practice, estimates for produced capital from the standard national accounts, based on exchange-value concepts, are often combined with estimates for other types of capital based on shadow prices. Hence, there may be a lack of alignment among the valuation concepts used to estimate various capitals. With regard to natural capital, it is clear that the use of exchange values for ecosystem services would not fulfil the conceptual requirements of wealth accounting, although there will be strong connections between the two approaches.

8.54. A second approach to integration, which builds on the use of restoration costs as a measure of ecosystem degradation, entails recording corresponding ecological liabilities on the national balance sheet. That is, unpaid restoration costs, which arise when an ecosystem declines in condition, are treated as a liability. This approach is described as a possible extension in the Ecosystem Natural Capital Accounts Quick Start Package (ENCA-QSP) and has also been suggested for use at the corporate level by the Natural Capital Committee (United Kingdom). From a national accounting perspective, there are a number of difficulties associated with this approach:

- First, there is the question of whether restoration costs is a suitable estimate of ecosystem degradation, as discussed in chapter VII;
- Second, there is a question of when liabilities should be recognized. If there is no expectation that the restoration will occur, then, at least for accounting purposes, no liability should be recognized. In effect, recognizing these liabilities represents, in the first instance, a social or analytical choice rather than an application of accounting principles;
- Third, if a liability is recognized, then, all else being equal, net wealth should decrease by that amount. However, since the recognition of the liability reflects the degradation of an asset, there is both a decrease in an asset and an increase in a liability for the same event, which implies a double-counting on the balance sheet in terms of the impact on net wealth. That issue does not arise in the integrated accounting approach, as already described in the present chapter, since the only balance-sheet change is the decrease in the asset value due to degradation. An alternative solution to the double-counting issue is to record the liability but keep the ecosystem asset value unchanged, although that seems counter-intuitive.

8.55. Overall, while recording ecological debts may appear to be an attractive objective and may be a useful tool in communicating the extent of ecosystem degradation, it has some deficiencies in terms of its consistency with national accounting principles.

8.56. The final integration approach to be described here is full-cost accounting, which has been developed in corporate accounting. The aim in full-cost accounting is to estimate and record the broader costs of a company's impacts on the environment as part of its ongoing operating costs, which thus results in an adjusted profit and loss statement. For example, the costs of greenhouse gas emissions and the release of pollutants are common areas of interest. Such information may be helpful in a range of management situations.

8.57. From an ecosystem accounting perspective, a few points may be highlighted. First, the approach largely excludes consideration of ecosystem services as inputs to the production process. Hence, in the full cost accounting approach, there is no change in the standard production or income boundaries.

8.58. Second, there is no recognition of ecosystem assets as part of a company's capital base and hence no impact of those assets on the company's balance sheet or recording of ecosystem degradation as a capital cost. Such degradation would be included implicitly in the adjusted profit and loss statement to the extent that it was part of the derivation of costs associated with the specific impacts assessed, but that would not be a specific focus.

8.59. Third, the incorporation of costs associated with residual flows (emissions, pollutants, etc.) is not undertaken directly in ecosystem accounting. In broad terms, a focus on residual flows reflects the valuation of a company's negative externalities, and externalities are specifically excluded from the national accounts. It may be that, in fact, the attribution of those costs can be part of a measure of ecosystem degradation. Further work is required to build an understanding of the links between the valuation of externalities and ecosystem accounting, with the understanding that those links may be different for different types of externalities.

8.60. Overall, while full cost accounting does represent a form of integration, it is somewhat different in scope and intent relative to the concepts and intent of ecosystem accounting.

8.8. Recommendations

8.61. An important facet of SEEA, from a national accounting perspective, is its potential to record the full integration of ecosystem accounting information into the standard national accounts and the derivation of adjusted estimates of GDP and other measures of economic activity. While there is recognition of the need for additional discussion, particularly on the allocation of degradation, through the adoption of ecosystem accounting, it has been demonstrated that a full integration is conceptually possible.

8.62. At the same time, numerous important measurement challenges exist that must be worked through and that are related, in particular, to the aggregation of stocks and flows across ecosystem services and ecosystem assets. While the present chapter has described some specific integration-related issues, the measurement issues raised in other chapters are equally relevant to the work directed towards the formation of a complete integrated accounting data set.

8.63. While work continues on developing full linkages between ecosystem and economic data, other options can be pursued. Combined presentations, as described in this chapter and in SEEA EEA, chapter VI, are important tools for presenting data that support a comparison and discussion of environmental and economic issues. It is strongly recommended that countries work towards the development of combined presentations of data. Work in that area is likely to receive considerable support from a focus on presentation of data at a meaningful spatial level.

8.64. As work on ecosystem accounting proceeds within a country, it is important that any similar or related work on the integration of environmental and economic data be placed in context. Generally speaking, types of data should be viewed not as being in competition but rather as being specifically suited for different purposes. Within such a framework, national statisticians have an important role to play in explaining the links between various measurement approaches and policy questions.

Chapter IX
Thematic accounts

Key points

- Thematic accounts are stand-alone accounts on topics of interest in their own right and also of direct relevance to the measurement of ecosystems and assessment of policy responses.
- The thematic accounts described in the present chapter cover land, carbon, water and species-level biodiversity and reflect the discussion of the accounts in SEEA Central Framework (on land and water) and in SEEA EEA (on carbon and species-level biodiversity).
- The development of land accounts, which can focus on land use, land cover or land-ownership, provides a platform for measurement and is commonly the basic entry point for ecosystem accounting.
- In water accounting, measurement at the water catchment level is important for ecosystem assessment. Work at that level, which requires the use of hydrologic models, can also underpin the estimation of relevant ecosystem services, such as water filtration and soil retention.
- Accounting for stocks of carbon can provide a strong base for coordinating information on carbon and complements measurement within the framework of the Intergovernmental Panel on Climate Change and the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN REDD+). The data can support measurement of ecosystem condition and ecosystem services such as carbon sequestration.
- Accounting for biodiversity considers both ecosystem and species-level biodiversity. Biodiversity is considered primarily a characteristic of ecosystem assets rather than an ecosystem service, which, in accounting terms, enables the recognition of declines or improvements in biodiversity over time and supports understanding of the capacity of ecosystems to supply ecosystem services.
- For all such accounts—for land, water, carbon and biodiversity—there is a broad range of information and measurement methodologies available. The challenge for ecosystem accounting is the assessment and integration of the data and methods within the SEEA EEA framework.

9.1. Introduction

9.1. The ecosystem accounts described in earlier chapters provide coherent coverage of information pertaining to ecosystem assets and ecosystem services. At the same time, a systems-only focus can pose challenges from both an analytical and a measurement perspective. More commonly, our view of ecosystems, and our policy responses, are framed by themes encompassing specific aspects of the economy–environment relationship. Four themes that are consistently in evidence are land, water, carbon and biodiversity. The present chapter, which examines ecosystem accounting within the context of those themes, reflects the more detailed examination of thematic accounts presented in SEEA Central Framework and SEEA EEA. The incorporation of a thematic focus within the framework of ecosystem accounting provides two benefits.

9.2. First, the thematic focus enables a closer link to be established between the compilation of ecosystem accounts and likely areas of policy response as related, for example, to land management, management of catchments, carbon emissions policy and maintenance of protected areas.

9.3. Second, the data that are used to build an understanding of trends in thematic areas can also be used in the compilation of ecosystem accounts. Practically speaking, entries in the ecosystem accounts can be sourced from thematic accounts (e.g., estimates of water provisioning services can be derived from water accounts); and conceptually, each of a number of thematic accounts can be considered to measure distinct ecological functions or cycles (e.g., the carbon cycle and the hydrological cycle). In that sense, the thematic accounts support ecosystem accounting by providing a different—but comprehensive—body of information.

9.4. It is relevant to note that while measurement in each of the four main thematic domains is relatively well advanced, work on SEEA has highlighted the potential of accounting approaches for use in: (a) improving the coordination of data; and (b) revealing the links between themes.

9.5. SEEA Central Framework and SEEA-Water provide the conceptual foundation for land and water accounting. As a single element, carbon is a highly suitable subject for accounting. It has therefore been presumed that adapting its measurement to a broad accounting structure would be a relatively straightforward undertaking. The relevant concepts in that regard are described in SEEA EEA (sect. 4.4). The application of accounting principles for biodiversity continues to develop. Relevant suggestions for biodiversity accounting were introduced in SEEA EEA, section 4.5, and work in that area has continued, as attested by a 2015 UNEP-D report and ongoing testing.

9.6. Accounts for land, water, carbon and biodiversity contain much relevant information in their own right. Consequently, compilers of ecosystem accounts are encouraged to seek opportunities to promote use of the information presented in those thematic accounts as a basis for supporting discussions of environmental-economic issues. In particular, information derived from the thematic accounts, when presented in the context of measures of ecosystem condition and services, can provide users with an implement for establishing concrete linkages between ecosystems and policy choices.

9.7. The present chapter provides a summary of the relevant accounting issues associated with each of these four areas. Other potential thematic accounts are described in section 9.6.

9.2. Accounting for land

9.2.1. Introduction

9.8. Following the accounting principles and structures described in SEEA Central Framework, accounting for land, particularly land cover, is a common starting point for compilers of ecosystem accounts. A distinction is made here between land accounting and ecosystem extent accounts. Land accounting is considered to encompass the compilation of a variety of accounts utilizing different land-related classifications including land use/management, land cover and landownership. Application of those classifications requires linkages to standard SNA classifications of industry, including the International Standard Industrial Classification of All Economic Activities (ISIC), and the institutional sector. Land accounting incorporates both standard asset account structures and change matrices and tables that cross-classify aspects of land, for example, land cover with land ownership (by institutional sector)). Those various aspects of land accounting are covered in SEEA Central Framework, chapter V.

9.9. The ecosystem extent account (see chap. III) is an account that specifically records the area, and change in area, of ecosystem types. As the classification used for ecosystem extent accounting should reflect facets of both land use and land cover, the extent account is generally similar in structure to land accounts presented in SEEA Central Framework but different with respect to the types of areas being accounted for. At an aggregate or initial level, it may be necessary to define ecosystem type classes on the basis of land cover classes. In that case, the ecosystem extent account and the land-cover account, as described in SEEA Central Framework, are equivalent.

9.10. While the detailed ecosystem type classes may be different, as part of the accounts compilation process, the information from land-cover accounts can be used to help define the relevant spatial areas, to determine the extent of various ecosystem types at a broad level, to support an understanding of the links between ecosystem services supply and the beneficiaries of those ecosystem services and, finally, to facilitate the scaling of other data to finer and broader levels of detail.

9.11. Further, from an analytical and policy perspective, information on land cover can, at a national scale, provide important information on trends in deforestation, desertification, urbanization and similar forms of landscape change. While understanding those types of changes is not sufficient, as is recognized in ecosystem accounting, for understanding their effects on ecosystem condition or flows of ecosystem services, it is nonetheless a relevant starting point.

9.12. As noted in chapter III, the total area of a country may also be classified according to land-use or landownership criteria. An interim land-use classification is provided in SEEA Central Framework (table 5.11 and annex I). Landownership may be classified by institutional sector (corporations, government, households) or by industry (agriculture, manufacturing, retail, etc.). In some cases, a reasonably clear connection can be made between different classifications of land; for example, there is often a connection between tree-covered areas and forestry. However, the depiction of a simple integration of land-cover and land-use classes is not possible.

9.13. Information on land use and land ownership is important for the achievement of an understanding of the connection between ecosystem assets and the users of ecosystem services. For that reason, it is recommended that, where possible, accounts for land use and landownership be compiled following the advice set out in SEEA Central Framework. A useful output for ecosystem accounting may be a table that cross-classifies land cover and land use at a given point in time. Such a table would highlight the relative significance of different land-cover types to specific uses.

9.14. Land accounts can also serve as an important tool for linking environmental and socioeconomic data, which would essentially provide a means of placing policy in a spatial context. One key link entails recognizing that policy implementation aimed at maintaining and restoring ecosystem condition is likely to require the involvement of landholders. Hence, an understanding of the connection between landownership, current use and the relevant ecosystem types can provide the means of decision-making on appropriate policy interventions.

9.15. Generally, the initial focus of land accounting is the terrestrial areas of a country, including freshwater bodies. Often, relevant national classifications and data sets exist. Within that scope, land must be divided into various classes (type of cover, type of use, or type of owning economic unit). On the other hand, it must be recognized that establishing an alignment or correspondence with international classifications is a highly important positive step. Chapter III discusses issues of classification in more detail.

9.16. As recognized in chapter III and SEEA Central Framework, accounting for ecosystem extent and land can be extended to encompass marine and coastal areas. As indicated in chapter III, work on marine and coastal ecosystems in an ecosystem accounting context is developing, and no further articulation in that regard is provided in the present chapter.

9.17. The basic structure of a land account follows the structure of an asset account as described in SEEA Central Framework, which encompasses an opening stock, additions and reductions in stock and a closing stock. Ideally, changes in stock over an accounting period are separated into those that are naturally driven and those that are the result of human activities.

9.18. Information on land cover and land use may be organized in the form not only of asset accounts but also of properly vetted and quality-controlled change matrices that show how, over an accounting period, the composition of land has changed. Table 5.14 of SEEA Central Framework is an example of such a land-cover change matrix.

9.2.2. Relevant data and source materials

9.19. Ivanov and Eigenraam (2015) discuss the compilation of land accounts in more detail. In terms of data requirements, their technical note distinguishes between dynamic and permanent features. Data on dynamic features include information on land use, land cover and vegetation type, while data on permanent features include information on administrative boundaries, ecological regions and river basins. Combinations of both administrative boundaries and ecological regions, as reflected, for example, in Canada's census metropolitan area-ecosystems (Statistics Canada, 2016), can also be developed when appropriate.

9.20. The compilation of accounts generally require that the various data be brought together using GIS so that data for a country as a whole can be produced. The aim in accounting terms is to generate harmonized maps, in time series, that enable stock and changes in stock to be consistently accounted for.

9.21. Materials utilized to support land accounting include SEEA Central Framework, SEEA EEA and ENCA-QSP. In particular, ENCA-QSP provides an extensive discussion of land cover accounting and associated data sources and methods.

9.22. Country examples and case studies offer additional support and guidance. Relevant in that regard is the work of the European Environment Agency (Weber, 2011); the Australian Bureau of Statistics (2015); Statistics Canada (2013); the Victorian Department of Sustainability and Environment (Australia) (Eigenraam, Chua and Hasker, 2013); the Indian Ocean Commission and the Government of Mauritius (Weber, 2014b), among others.

9.2.3. Key issues and challenges relating to measurement

9.23. There are a range of measurement challenges posed by land accounting. One challenge—and an immediate one—entails integration of the various data to produce harmonized geodatabases and, for accounting purposes, measures of change over time. That requires careful consideration of scale and classification for different data sets at the same point in time and for the same data set at different points in time.

9.24. In general terms, while higher levels of detail are preferable, they are at the same time associated with higher resource costs. It will be important to achieve a balance in terms of the availability of resources and the necessary degree of accuracy. A relevant requirement in this context is an understanding of the existing approaches to the validation of data, particularly since many of the data will be derived from remote sensing (Earth observation) sources, including satellite imagery. Ideally, sampled "ground truthing" at some level, or another quality-control and data confrontation process—for example, comparison with administrative data or with information derived from agricultural or population censuses or other sources—must be undertaken.[49]

9.25. The Land Use and Coverage Area frame Survey (LUCAS) has been carried out by Eurostat every three years since 2006. It was developed on the basis of an integrated approach involving sampled reference points to measurement of land use and land cover across Europe. That approach may stimulate further thinking on how to conduct measurement at the national level.

9.26. The approach to classifying land is particularly important as a means of communication regarding the changing composition of land at the national level. There now exists a confirmed International Organization for Standardization (ISO) standard for land cover[50] that underpins the Land Cover Classification System version 3, as developed by FAO (FAO and Global Land Cover Network, 2009). That provides a structure based on which each type of land cover worldwide can be classified consistently, thereby providing a means of linking the various land-cover classifications that are in use in various countries and regions.

9.27. Compared with the Land Cover Classification System, which is a base-level classification tool, the approaches to the definition and formation of higher-level classes, which can be used to summarize detailed classes in meaningful ways, have been more varied. There are a number of options, one of which is the interim land-cover classification presented in SEEA Central Framework. Establishing a broadly accepted set of high-level classes of land cover (say 10 to 15)—and the associated definitions of those classes—would be a significant step forward in coordinating information and would further underpin greater alignment in ecosystem accounting discussions and applications. At the same time, a smaller number of classes may be most appropriate for analysis of changes over time, to ensure that the measurement of change is as accurate as possible.

9.28. SEEA Central Framework interim land-use classification comprises seven high-level classes of land use based on the work of FAO on land use for agriculture, forestry and fisheries, and that of the Economic Commission for Europe on the classification of land use for all economic activities. SEEA Central Framework classification also incorporates classes covering inland water, coastal waters and marine areas extending to a country's exclusive economic zone. The finalization of classifications for land use and land cover is a priority in the research agenda of SEEA Central Framework.

9.29. It should be recognized that the use of land-cover and land-use data reflects the effort to represent a three-dimensional world in two dimensions, which, within the context of multiple-class data sets, can lead to significant trade-offs related to

[49] For example, FAO has used sampled locations through Google Earth to "ground truth" its satellite-based estimates of land cover.

[50] ISO 19144-2:2012 specifies a land cover metalanguage expressed as a unified modeling language metamodel, which allows land-cover classification systems to be described based on physiognomic aspects. See www.iso.org/standard/44342.html.

measurement of individual classes and potential biases. In particular, for a given ecosystem type (e.g., wetlands), comparing the results produced through use of multiple-class land-cover data sets with those produced through use of a single-class data set designed specifically for that particular ecosystem type will likely reveal differences. It is recommended that, where possible, information from single-class data sets be used and integrated within the broader coverage required for the accounts.

9.2.4. Recommended activities and research issues

9.30. It is recommended that countries develop land accounts as an integral part of a suite of national environmental-economic accounts. Land accounts, in their own right, provide important information on environmental trends. Further, their compilation requires the organization of spatial data, which in turn serve as inputs for the delineation of spatial units and ecosystem accounting. Finally, a focus on land provides a platform for integrating environmental and socioeconomic data.

9.31. Chapter III presents several areas relevant to the testing of land accounts within the context of the delineation of spatial units and the compilation of ecosystem extent accounts. With regard to areas of research, the main issues, beyond those already noted in that chapter, are related to: (a) finalizing appropriate classifications for land cover and land use extending beyond the interim classifications in SEEA Central Framework; and (b) determining the best approaches to accounting for linear features, such as rivers, beaches and hedgerows.

9.32. From a practical perspective, testing and additional advice needs to be provided on:

- Interpretation of land-cover and land-use data, particularly in the context of utilizing remote sensing and satellite data;
- Achieving an understanding of the appropriate scale for land accounts and the measurement of spatial areas;
- Techniques for controlling land-cover and land-use data sets for quality, especially techniques related to ground truthing data;
- Methods for developing time series of data on land-cover and land-use change, including the use of information on disturbances such as forest fires;
- Approaches to identifying key and rare ecosystem types that may be relatively small within a national context.

9.3. Accounting for water-related stocks and flows

9.3.1. Introduction

9.33. Water is a fundamental resource. It is essential for all life and, in many countries, underpins the production of food, fibre and energy. Water management—which includes taking into account cross-boundary flows (e.g., the Nile River) and joint ownership of surface-water bodies (e.g., Lake Victoria)—is an important focus for many Governments worldwide.

9.34. Accounting for stocks and flows of water is a key feature of SEEA Central Framework, SEEA-Water and SEEA EEA. Whatever the context, accounting for water resources should be undertaken following the standard advice provided in SEEA Central Framework. The intention in the present short section is to direct attention to relevant technical and compilation-related material rather than to reproduce—or even summarize—the content of SEEA manuals.

9.35. Accounting for water is relevant to ecosystem accounting in a number of ways. First, as water is a key feature of ecosystems, the measurement of the stocks and changes in stocks of water resources is a relevant facet of the measurement of ecosystem condition. While accounting for changes in water quality is another important contribution to ecosystem accounting, this area of water accounting is not well developed from a SEEA perspective.

9.36. Second, there are a number of ecosystem services that relate directly to water. Those include the provisioning service of water when it is abstracted for use (e.g., in irrigation, drinking, hydropower), the regulating service role of water bodies in filtering pollutants and other residual flows, and the cultural services associated with water, such as fishing and other recreational activities. In addition, there are a number of ecosystem services to which water is linked, for example, provision of flood protection benefits through the regulation of water flows and water filtration by ecosystem assets.

9.37. Measurements in all of those areas are ultimately important within a complete set of ecosystem accounts. The water resource accounts of SEEA Central Framework and SEEA-Water focus on two areas: (a) supply and use of water; and (b) the asset account for water. They provide the basis for accounting for stocks and flows of water. It is of particular note that such accounting can be undertaken at a subnational level and in that regard, compilation at catchment level is recommended.

9.38. At the level of the individual water catchment or basin, information may be available—for example, on temperature, precipitation, population density, nutrient flow, barrier density and fragmentation—that would enable each catchment to be characterized. Such information supports the compilation and interpretation of ecosystem accounts.

9.3.2. Relevant data and source materials

9.39. There are many relevant materials that provide support for the compilation of water accounts, which include not only SEEA Central Framework and SEEA EEA but also SEEA-Water and its companion volume, *International Recommendations for Water Statistics* (United Nations, 2012a). ENCA-QSP, chapter 6 (Weber, 2014a), also contains much relevant information.

9.40. There is a wide range of data sources, including global data sets that might be considered suitable for use in water accounting. Vardon (2014b) provides both a good overview including links to those data sources and a description of some relevant country examples. In certain cases, the use of GIS tools is relevant to the estimation of water stocks and flows in areas that are not regularly gauged or for which observed data are not available. To date, over 50 countries have trialled the development of SEEA-based water accounts. Consequently, there is an increasing body of broad-ranging knowledge and experience in water accounting that can be drawn upon readily.

9.3.3. Key issues and challenges relating to measurement

9.41. Accounting for water still poses some specific challenges, especially within an ecosystem accounting context. Linked to the issue of defining spatial units is the need for clarity with respect to the delineation of wetlands. The scale of analysis in that regard is a particular area of concern, since many wetlands may be quite small but at the same time disproportionately important within the context of larger land-cover types (e.g., grasslands).

9.42. To date, ecosystem accounting has generally focused on surface-water resources. However, if information pertaining to the hydrological cycle is to be more fully incorporated, integration of information on groundwater within the ecosystem accounting framework requires further consideration. The incorporation of information on the atmosphere would also be relevant in this context.

9.43. Integration of information on stream flow and water yield is also appropriate. While these are not standard SEEA accounting entries, indicators on those aspects of the hydrologic system are relevant to understanding the system and assessing ecosystem condition more completely. Indeed, in some countries with very large stocks of water resources, understanding the stock of renewable water, based on information on stream flow and water yield, may be of direct use in understanding the relationship between water resources and socioeconomic activity.

9.44. Given that water flows are often key pathways connecting various ecosystems, more work is needed to enable an understanding of and accounting for flows of intermediate ecosystem services and dependencies between ecosystem assets that are related to water. For example, understanding water flows is relevant in measuring the service of soil retention within a water catchment. SEEA EEA largely ignored flows between ecosystems, but subsequent deliberation has suggested that incorporating certain intermediate ecosystem services should be required.

9.45. A general challenge in water accounting is associated with the fact that from a national accounts perspective, national data on stocks and flows of water resources may not be highly meaningful. Standardized information at a catchment level may be required instead. However, a straightforward suggestion that measurement should be carried out at that level of detail must include the recognition that developing estimates at a catchment level will be resource-intensive. Further, in some situations, subannual (including daily) data may be needed to enable an understanding of the dynamics of seasonal fluctuations in water supply and water use (e.g., Statistics Canada, 2010). The opportunity to acquire that understanding will be missed if annual data or long-term averages are the sole source of information.

9.3.4. Recommended activities and research issues

9.46. The main conclusion to be drawn with respect to accounting for water resources is that there is a wide array of information on and examples of water accounting in practice to support countries that wish to begin work in that area. Further, there are many data sets that can provide a starting point for compilation. Testing the compilation of water accounts should therefore be given very high priority.

9.47. Vardon (2014b) highlighted a number of subject areas in which discussion might be advanced and further research conducted, for example accounting for dependencies between ecosystem assets within catchments, including flows of intermediate ecosystem services, valuation of water resources and accounting for water quality at a broad scale. Further, the integration of information on groundwater and atmospheric water complements the information in both water resource accounts and ecosystem accounts.

9.4. Accounting for carbon-related stocks and flows

9.4.1. Introduction

9.48. As carbon has a central place in ecosystem and other environmental processes, accounting for carbon stocks and the transfers between them must be viewed as an important dimension of environmental-economic accounting. The intention in the present short section is to direct attention to relevant technical and compilation-related materials rather than to reproduce—or even summarize—the content of those materials.

9.49. Accounting for carbon in SEEA commenced within the context of accounting for carbon stored in forests and for greenhouse gas emissions. Accounting for the stocks and flows of carbon was included in SEEA Central Framework. With the development of SEEA EEA, the scope of carbon accounting has been broadened. Ideally, it encompasses measurement of carbon stocks and flows for all parts of the carbon cycle and all carbon pools and thus covers geocarbon, biocarbon, atmospheric carbon, carbon in the oceans and carbon accumulated in the economy. In practice, the focus of carbon accounting at this stage is on biocarbon and geocarbon.

9.50. The measurement of stocks and flows of carbon can support discussion of many policy-relevant issues, including analysis with regard to greenhouse gas emissions, sources of energy, deforestation and land-use change, loss of productivity and biomass, and sources and sinks of carbon emissions. Since carbon is also a common focus of policy response—for example, through carbon taxes—its direct measurement has a high level of relevance.

9.51. In ecosystem accounting, information on stocks and flows of carbon may be utilized in two main areas. First, it may be considered a broad indicator for the measurement of ecosystem condition. For example, following Chapin and others (2006), changes in the net ecosystem carbon balance can be used as an indicator of ecosystem condition. However, it should be recognized that in many contexts, the stock of biomass carbon is generated through human actions (e.g., in the context of plantation forests) and consequently measures of the carbon balance provide poor measures of ecosystem condition if used as a proxy for the degree of naturalness of the ecosystem. Second, within ecosystem accounting, carbon accounts can be used in the measurement of ecosystem services, including carbon sequestration.

9.4.2. Relevant data and source materials

9.52. The structure of a carbon stock account is presented in chapter IV (table 4.6) of SEEA EEA. The compilation of that account, with its focus on biocarbon and geocarbon, involves the collection of: (a) data on land vegetation/cover and the rates at which different types of land/vegetation cover sequester and store carbon in above- and below-ground biomass; (b) data on the carbon content of soils; and (c) information on subsoil fossil fuel resources. A summary of relevant data sources and links to those sources is presented in Vardon (2014a). Information compiled by countries as part of their reporting to the secretariat of the United Nations Framework Convention on Climate Change, although not all land types are included under the Kyoto Protocol to the Convention,[51] is a source of particular relevance.

[51] *United Nations Treaty Series*, vol. 2303, No. 30822.

9.53. Advice on the compilation of carbon accounts is summarized in SEEA EEA. More detailed guidance is provided in Ajani and Comisari (2014), which describes the development of a carbon account for Australia, including a discussion of the relevance and application of the account.

9.54. A number of facets of carbon accounting are also covered in SEEA Central Framework. For example, air-emission accounts include flows of greenhouse gas emissions; and mineral and energy resource asset accounts record stocks and changes in stocks of subsoil fossil fuel resources. Within the SEEA framework, it should be possible to bring together all of the information on those various components of the carbon cycle to produce a coherent picture of a country's carbon stocks and flows. For the purposes of SEEA EEA, compilation of carbon accounts at a finer level of spatial detail—for example, by ecosystem asset or ecosystem type—it is key requirement.

9.55. ENCA-QSP provides a detailed discussion on accounting for changes in biocarbon at national scale, including consideration of global data sets and measurement challenges. Of particular relevance is the work on the measurement of carbon undertaken through the FAO Global Forest Resources Assessment (see, FAO, 2015), which is conducted every five years. The Forest Resources Assessment requests estimates of carbon stock for forests including above- and below-ground carbon stocks. Those data may provide a useful starting point for compilation of a time series of carbon accounts, as well as a level of detail by type of forest that is sufficient to enable the interpretation of changes in the carbon balance to be better associated to changes in ecosystem condition.

9.4.3. Key issues and challenges relating to measurement

9.56. The measurement issues associated with carbon, compared with those in the other areas of ecosystem accounting discussed in this chapter, have been relatively well researched. That reflects the fact that substantial resources have been invested in the measurement task within the framework of Intergovernmental Panel on Climate Change processes. Nonetheless, there are important issues of data quality that still need to be considered. There are also challenges related to: (a) using point measurements for estimation of carbon stocks across large areas; and (b) accounting for the wide variety of vegetation and soil types, given that different carbon content ratios apply in different situations. There is a related issue: the sourcing of information either through remote sensing or through the use of local sources requires that a balance be struck between coverage and accuracy.

9.4.4. Recommended activities and research issues

9.57. Given the high degree of policy relevance of carbon and the comparably high level of resources channelled into measuring stocks and flows of carbon at national level, it is recommended that countries support the development of carbon accounts. The preparation of those accounts can provide not only information on broad trends in environmental change but also insight regarding the requirements for bringing data together from a variety of sources.

9.5. Accounting for biodiversity

9.5.1. Introduction

9.58. Biodiversity—the diversity of ecosystems, species and genes—plays an essential role in supporting human well-being. Biodiversity helps maintain the functioning and resilience of ecosystems which in turn deliver ecosystem services such as food, climate regulation, and aesthetic enjoyment and other cultural benefits.

9.59. SEEA EEA provides a framework for measuring ecosystem service flows supported by biodiversity and other characteristics (e.g., soil type, altitude) and linking them with the economy and other human activities. It also enables the comparison and integration of data on ecosystem services with other economic and social data. Biodiversity accounts, in conjunction with the ecosystem accounting framework, can therefore help build an understanding of the relationship between biodiversity and economic activity.

9.60. Generally speaking, from the perspective adopted in SEEA EEA, biodiversity is a characteristic that is directly relevant to measurement of the condition of ecosystem assets. Indeed, conceptually speaking, measures of biodiversity are considered to be measures primarily of ecosystem assets in the accounting model. Thus, potential connections to biodiversity, such as birdwatching or fishing, are regarded as being benefits derived from biodiversity rather than as being flows of biodiversity services in their own right. That approach is consistent with a view that biodiversity can be degraded or enhanced over time, an attribute that applies only to assets within an accounting context.

9.61. Further, people may show an appreciation for, and thereby demonstrate that they value, specific elements of biodiversity, such as endemic and iconic species. The desire to conserve those species has resulted in the creation of protected areas in many countries. Such species can survive in the long term only when the overall condition of the ecosystems in which they exist is maintained—a dynamic whose logic highlights the interplay among the measurement of specific ecosystem services, the existence of individual species and the nature of ecosystem condition. The discussion of biodiversity in accounting for ecosystem stocks and flows must therefore be conducted with appropriately careful deliberation.

9.62. In the framing of SEEA EEA, species-level biodiversity may be considered a characteristic of an individual ecosystem asset or of connected ecosystem assets, for example, ecosystem assets linked through the patterns of migration of certain species. Measures of ecosystem-level biodiversity reflect the diversity of ecosystem types, depending on the suitability of the classification of those ecosystem types.

9.63. Notwithstanding the connection made here between biodiversity measurement and the measurement of ecosystem assets, there are situations in which measures of biodiversity can be indicators of flows of final ecosystem services. For example, biodiversity indicators may be related to the value of recreational services from wildlife-related activities, through which people reap the benefits of experiencing the diversity of nature, as distinct from services received through an appreciation of individual species. In those circumstances, it is relevant to recognize that measures related to biodiversity may be appropriate indicators in a variety of accounts, including ecosystem condition accounts and ecosystem services supply and use accounts.

9.64. Aside from supporting ecosystem accounting, biodiversity accounting provides opportunities for the harmonization of national-level biodiversity data with the data generated by other reporting mechanisms. Those mechanisms include the national biodiversity strategies and action plans implemented under the Convention on Biological Diversity and the follow-up and review process related to the implementation of the Sustainable Development Goals.

9.65. A range of biodiversity indicators should be considered for utilization in portraying the multilayered relationship among biodiversity, ecosystem functioning, ecosystem services and human appreciation of ecosystems. A species indicator could be selected on the basis of the importance of that species: (a) for specific ecosystem processes; (b) as a signifier of ecosystem condition or functioning; or (c) as an embodiment of specific features of biodiversity (e.g., the abundance or scarcity of threatened, endemic and/or iconic species) that elicit human appreciation.

9.66. Integrated accounting for the facets of biodiversity is still under development. As the experimentation carried out by countries on biodiversity accounting is less advanced than, for example, experimentation for water and carbon accounting, a technical note was commissioned under the Advancing Natural Capital Accounting (ANCA) project to advance that work (UNEP-WCMC, 2015). That led to a follow-up workshop and the issuance of a publication specifically focused on exploration of approaches to accounting for species in the context of SEEA EEA (UNEP-WCMC, 2016). The present section summarizes the findings presented in those outputs but does not attempt to provide definitive descriptions of biodiversity or its measurement.

9.5.2. Assessing ecosystem and species biodiversity

9.67. Assessments of biodiversity generally consider ecosystem and species biodiversity. Assessing genetic biodiversity is constrained by the factors of cost and complexity. However, as genetic biodiversity is an important phenomenon, it may be integrated into ecosystem accounting in the future.

9.68. If data are to be considered suitable for accounting for biodiversity, ideally, those data should meet the following general criteria:

- They should be accessible at a spatial resolution suitable for accounting, which would allow data to be mapped to individual ecosystem assets and types;
- They should be temporally relevant so as to inform net changes in the stock of biodiversity between the opening and closing of accounting periods;
- They should be comparable with a common reference condition, which would allow the comparison of biodiversity measures against a benchmark indicative of a balanced state and aid in the aggregation of different types of biodiversity data;
- It should be possible to aggregate the measures to produce a composite indicator of the condition of biodiversity (through use, e.g., of the Simpson index or a common reference condition). The change in that composite indicator between accounting periods would provide an indication of the net biodiversity balance;
- They should be comparable over space and time, which would enable direct comparison of biodiversity stocks in different ecosystem types.

9.69. Ecosystem biodiversity may be assessed using information on ecosystem extent (see chap. III). Extent measures are based on data on land cover, land use and habitat, as well as other ecosystem data, commonly sourced from satellite remote sensing. Within the SEEA EEA framework, those data inputs also provide spatial information for delineation of ecosystem assets on the basis of common characteristics. Many countries have their own ecosystem classifications and standard methods for mapping them, and work is progressing towards establishing an internationally accepted ecosystem classification.

9.70. In accounting for ecosystem biodiversity, it may be useful to supplement information within the ecosystem extent account with more detailed information on species-related characteristics, including vegetation classes and community composition. To best support integration, work should be undertaken in the context of the spatial areas defined for ecosystem extent accounting rather than those defined for land-cover accounts (see SEEA Central Framework, e.g., chap. V, sect. 5.6).

9.71. Given that ecosystem biodiversity is captured in the ecosystem extent account, the focus of thematic biodiversity accounting in the present chapter is on species biodiversity. Ideally, the development of a biodiversity account using species data should move beyond simple counts of the number of species (species richness) to include the population size of each species (species abundance), as that provides more information on the status of species.

9.72. The International Union for Conservation of Nature (IUCN) Red List of Ecosystems Categories and Criteria (Keith and others, 2013) will in due course meet the criteria in paragraph 9.68 by generating measures of ecosystem condition based on the risk of ecosystem collapse. The spatial resolution (anticipated to be at least 250 metre resolution) will be high enough for use in national ecosystem accounting. The first global assessment (scheduled for 2025) will provide a baseline which may then be used as a reference condition. Assessments are likely to be repeated on a five-year basis. The application of the quantitative categories and criteria will ensure consistency and comparability between countries and over time.

9.73. With regard to species biodiversity data, three tools which are relevant to different thematic biodiversity accounting concerns are mentioned here: the IUCN Red List of Threatened Species (IUCN, 2014); the Norwegian Nature Index (NNI); and the Living Planet Index (LPI). The IUCN Red List of Threatened Species measures extinction risk. Application of the IUCN Red List categories and criteria ensures consistency of assessment over space and time and between assessors. While the Red List Index was designed originally for global assessments, methods are available to allow disaggregation of the Index to national levels. The global Red List downscaled to national levels can be complemented with national red lists, where these exist. It is suggested that both the global Red List and national red lists be used to ensure as broad and relevant a coverage as possible.

9.74. The Norwegian Nature Index (Certain and others, 2011) uses indicators from a variety of species groups and major ecosystem types that measure deviation from a reference state. That index produces a single "value" which provides information on the condition of species biodiversity and other characteristics within ecosystems. The Norwegian Nature Index incorporates expert judgment, and monitoring- and model-based estimates, which enables the method to be used in both data-rich and data-poor areas.

9.75. The Living Planet Index (World Wide Fund for Nature, 2014) aggregates species population trend data from different sources and across multiple spatial scales. The methodology entails a series of aggregations through which the bias that would be induced by inclusion of only well-known taxonomic groups and well-studied locations is avoided. Given the systematic monitoring of species abundance, the data are suitable for incorporation in an accounting format.

9.76. Fully comprehensive documentation and description of species biodiversity presents a challenge owing to the large number of species and species occurrences, even in relatively species-poor environments. Consequently, measures of ecosystem biodiversity obtained by accounting for ecosystem types can provide a useful "coarse-filter surrogate" for species biodiversity. If ecosystem biodiversity is reasonably well documented through the mapping and classifying of ecosystem types, then, when ecosystem biodiversity is accounted for, much species biodiversity will be accounted for as well. For example, a decline in ecosystem biodiversity would likely be accompanied by a decline in species biodiversity.

9.77. There are a number of designations for ecologically important places that can support species biodiversity measurement. Those designations include "Key Biodiversity Area (KBA)"; "Alliance for Zero Extinction (AZE) site"; "biodiversity hotspot", as identified by Conservation International; "national park" and "nature reserve".

Accounting for the extent of these areas would also provide useful information on potential trends in species status.

9.5.3. Implementing biodiversity accounting

9.78. A key starting point for biodiversity accounting is the identification of biodiversity-related policy priorities to help determine what information, covering plants, animals and, to a lesser extent, fungi, should be compiled. That step also establishes the required resolution of data, both spatial and temporal, necessary to address these priorities.

9.79. Establishing an inventory of all existing monitoring data helps identify any data gaps. Such identification of data gaps could inform a protocol for further data gathering (e.g., through monitoring or modelling approaches). Countries should also consider their reporting obligations to regional processes and biodiversity-related conventions and agreements, such as the Convention on Biological Diversity and the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention).[52]

[52] *United Nations Treaty Series*, vol. 996, No. 14583.

9.80. Developing measures of species biodiversity is both resource-intensive and associated with methodological challenges. As the complete inventory of a country's species is not possible, those species to be included in an account need to be prioritized. Some species (e.g., keystone or umbrella species) are better indicators of biodiversity and ecological condition than others. Species may be of particular relevance because of their functional roles (e.g., pollinating species), or their cultural importance (e.g., sacred plants and animals) or because of conservation-related concerns (e.g., threatened species). With regard to the selection of species, the broader the representation of taxonomic groups (e.g., plants, birds, mammals, etc.), the better the account's estimation of overall biodiversity (see Remme, Hein and van Swaay, 2016, for details). Further, it may be useful to construct accounts for groups of species (e.g., taxonomic, trophic or functional groups) rather than accounts that focus solely on individual species.

9.81. Any prioritization exercise should be driven by the intended uses of the biodiversity accounts. Responding to a range of biodiversity-relevant policy questions may require the construction of more than one species biodiversity account. For instance, UNEP-WCMC (2016) proposes that prioritized species or species groups be organized in either holistic accounts or in separate accounts for:

(a) Species of conservation-related concern;

(b) Species important for ecosystem condition and/or functioning;

(c) Species important for ecosystem service delivery.

UNEP-WCMC (2016) notes that those accounts could be supplemented, or substituted where data are limited, by accounts for Red List status and/or accounts for the extent of important places for species (key biodiversity areas, national parks, etc.).

9.82. In the measurement of species biodiversity, it is important to distinguish between quantity and variability. Considering species biodiversity in terms of quantity (e.g., abundance) is important when accounting for the stock of particular facets of biodiversity is of interest. However, that does not reflect the emphasis on variability inherent in the definition of biological diversity as provided in article 2 of the Convention on Biological Diversity.[53] When applied to species, this variability is expressed as alpha diversity within communities, beta diversity between communities or gamma diversity within a landscape. Therefore, when creating a species account, analysts

[53] *United Nations Treaty Series*, vol. 1760, No. 30619.

should consult with ecologists to ensure that meaningful data are collected and collated and that accounts are constructed, at the scale that captures the aspects of biodiversity that are relevant to the anticipated uses of the accounts.

9.83. While utilization of primary direct-observation data on biodiversity is the ideal, it is unlikely that such data will be available at the spatial resolution required for ecosystem accounting in most countries. A number of habitat-based approaches—including the use of preferred habitat or land-use modelling and methods involving species-area curves and expert judgment—are available for upscaling or downscaling data on species biodiversity so that species status can be estimated. A portfolio of these approaches is required to inform biodiversity accounting. It is important however, that any application of those approaches be supported by regular updating of primary monitoring data and that, as far as possible, national data be used to underpin modelling approaches.

9.5.4. Limitations and issues to be resolved

9.84. Accounting tables should be designed to organize information in such a way as to enable it to be scaled, aggregated and compared with information for other areas of ecosystem accounting. Given the generally heterogeneous nature of species data, and the variation in species assemblages both among ecosystems and among locations, that is not easily achievable at present. Application of reference condition-based aggregation approaches may be possible but further research is required on how measures of status for different species can be meaningfully aggregated across species, ecosystems and geographical domains.

9.85. In their present state, the majority of potential global data sets do not provide the temporal or spatial resolution necessary to inform national biodiversity accounting. Further, development of biodiversity accounts that are globally comparable is likely to be challenging, particularly when relative measures of biodiversity are employed, since that requires a consistent reference condition.

9.86. While a single biodiversity indicator may provide an overall perspective on ecosystem condition for an ecosystem asset, it is unlikely to be useful as regards informing the link between biodiversity and ecosystem service supply, since different aspects of biodiversity are relevant to different ecosystem services. Consequently, a broad suite of biodiversity indicators is likely to be required. For those species considered to provide an ecosystem service directly (e.g., through their simple existence or the generation of aesthetic enjoyment), information contained within a species biodiversity account can directly inform ecosystem service supply estimates.

9.87. Finally, the value of the contribution of biodiversity to ecosystem service supply and subsequently to economic and human activity may be recorded in the ecosystem accounting framework. Various market-based and non-market-based valuation techniques exist for generating values for certain aspects of biodiversity (e.g., TEEB, 2012). However, this is possible for only a subset of ecosystem services for which production functions can be described and the marginal value of biodiversity will likely remain implicit in the estimated values of the majority of ecosystem services.

9.5.5. Recommendations for further research and testing

9.88. A range of topics can be the focus of further research and testing. First, additional testing of suitable spatial scales for biodiversity accounting is required. That should be supported with further testing, via various downscaling and upscaling techniques, of modelling and other approaches for generating spatially explicit information on the status of biodiversity, building on those approaches explored in UNEP-WCMC (2016). Protocols for validation and calibration of such approaches should also be explored.

9.89. Selecting the appropriate scale has significant implications for the aggregation of biodiversity information. Thus, further research and testing of methods for aggregating ecosystem and species data and indicators across ecosystem units is required. That should include a focus on how indicators of ecosystem biodiversity could be calculated using information from the extent accounts. In particular, the role of data on species (e.g., vegetation data), fragmentation, condition and the naturalness of ecosystems, and, ideally, the impacts of ecotones (i.e., areas of high biodiversity on ecosystem borders), need to be considered.

9.90. The biodiversity accounts proposed in SEEA EEA enable the causes of additions and reductions in the stocks of species biodiversity to be recorded. There are obvious advantages to be derived from recording such causal relationships. However, completion of the required entries, which would call for additional data collection, may often be difficult to achieve in a balanced manner. Testing within the context of a specific case study—possibly through linkages to landownership or land use—would be of benefit in gauging the possibilities for undertaking such work. At that stage, it is recommended that countries focus on the development of biodiversity time-series, displayed as a sequence of opening and closing positions.

9.91. As discussed in the present section, biodiversity is to be considered a potential indicator of condition in the ecosystem condition account. Ideally, improvements and reductions in biodiversity would also be recorded in the condition account. As multiple drivers of biodiversity loss exist, a supplementary account for drivers of change in ecosystem condition could be a possible subject of testing. That would also provide a suitable structure for capturing features such as habitat fragmentation and invasive species.

9.92. The link between biodiversity and ecosystem service delivery is a complex one. Often, there are time lags between changes in biodiversity and changes in the supply of ecosystem services. Furthermore, capturing information on the importance of biodiversity to ecosystem functional redundancy and resilience poses challenges owing to non-linear and threshold effects. Given the importance of biodiversity to ecosystem functioning and sustaining ecosystem service provision, addressing the measurement of ecosystem functional redundancy, resilience and thresholds should be regarded as a key issue within the ecosystem accounting framework. Further research is clearly required in that regard.

9.93. Finally, further research is required on the application of information derived from biodiversity accounts. That should entail examining: (a) the role of those accounts with regard to informing and monitoring policy actions (e.g., measuring progress towards achieving the Aichi Biodiversity Targets[54] and the Sustainable Development Goals); and (b) how to integrate them into the wider SEEA EEA framework.

[54] United Nations Environment Programme, document UNEP/CBD/COP/10/27, annex, decision X/1 and annexes.

9.6. Other thematic accounts and data on drivers of ecosystem change

9.94. As noted in the introduction to this chapter, a wide range of data needs to be integrated in the compilation of ecosystem accounts. Data on land, water, carbon and biodiversity are likely to be relevant across many ecosystem types. Other data areas, for which accounting frameworks have been developed in some cases, include:

- Timber resources (accounting for which is described in SEEA Central Framework);
- Fish and other aquatic resources (accounting for which is described in SEEA Central Framework);
- Other biological resources including livestock, orchards, plantations and wild animals (accounting for which is described in SEEA Central Framework);
- Soil resources (accounting for which is described in SEEA Central Framework, although further development is required);
- Nutrient flows and balances for nitrogen and phosphorus (accounting for which is described in SEEA for Agriculture, Forestry and Fisheries (FAO, 2016) and in OECD/Eurostat manuals (e.g., Eurostat, 2013));
- Greenhouse gas emissions and residual flows (e.g., solid waste, wastewater) (accounting for which is described in SEEA Central Framework);
- Data on production and use of outputs from agricultural, forestry and fisheries activity (accounting for which is described in SEEA for Agriculture, Forestry and Fisheries (FAO, 2016));
- Data on tourism and recreation (there is some coverage of accounting in *Tourism Satellite Account: Recommended Methodological Framework 2008*) (United Nations, World Tourism Organization, Commission of the European Communities and OECD, 2010) and in the developing statistical framework for measuring sustainable tourism (World Tourism Organization, 2017));
- Population data.

9.95. In other contexts, many of those types of data are considered indicators of drivers of changes in ecosystem condition and the supply of ecosystem services, that is, they point to the changing extent of human interaction with the environment. Information on drivers is likely to be of particular relevance to: (a) understanding changes in condition for specific ecosystems; (b) developing appropriate assumptions regarding future flows of ecosystem services; (c) assessing ecosystem capacity; and (d) valuing ecosystem assets.

9.96. It is to be noted that accounting has particular relevance for greenhouse gas emissions and other residual flows such as solid waste. While those flows are not treated as ecosystem services within the ecosystem accounting model, significant interest may nonetheless exist—given their potential negative impact on environmental condition—in determining how a narrative concerning residual flows may be incorporated in ecosystem accounting. In practice, the most straightforward first step is to present information on flows of emissions and residual flows by type of economic unit and by spatial area where possible, alongside information on changes in environmental condition for the same and nearby areas. Subsequently, through analysis, it may be possible to define linkages between changes in condition, the residual flows and associated economic units.

9.97. A more complete integration of residual flows into the ecosystem accounting model requires an understanding of dependencies between ecosystems. In particular, such integration requires the incorporation of the atmosphere as a type of spatial "area", whose condition is affected by economic activity (e.g., forest fires). In cases in which there is a decline in condition, it would be possible, within the ecosystem accounting model, to assess the effects on flows of ecosystem services and other environmental services, such as the provision of clean airspace for air transport. However, the extension just described requires further consideration.

9.98. It is likely that generation of the data at the appropriate spatial scale for ecosystem accounting will require some scaling and modelling of the information covered by the accounts listed in paragraph 9.94. The issue of scaling is discussed in Bordt (2015b).

9.99. Further, it is necessary, particularly for the measurement of ecosystem services, to use models of ecosystem processes to estimate the relevant flows. Those models will require additional data, usually of a scientific or ecological nature. Over time, as the accounts develop, investigation of the alignment and consistency between the scientific data and the socioeconomic data is likely to be possible , particularly as they pertain to specific spatial areas or ecosystems. In that context, the ecosystem accounting model provides both a rationale and a platform for data integration.

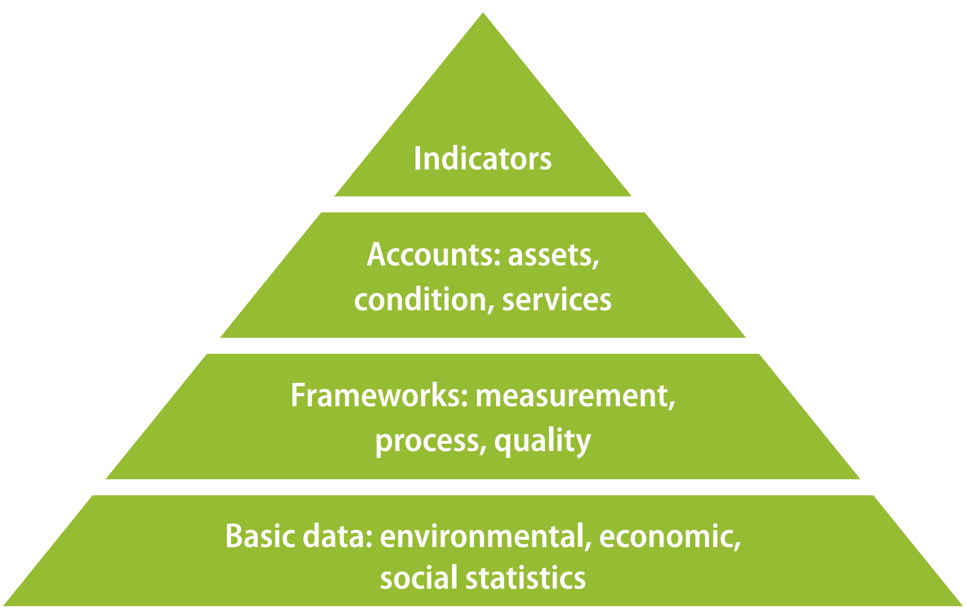
Annex I
Key features of a national accounting approach to ecosystem measurement

Introduction

A1.1. The present annex outlines the key features of a national accounting approach to ecosystem measurement and explains why this specific approach is highly effective in facilitating the mainstreaming of environmental information into economic measures.

A1.2. The information pyramid presented in figure A1.1 places accounting frameworks in context. The base of the pyramid comprises a full range of basic statistics and data from various sources including surveys, censuses, scientific measurements and administrative entities. Generally, those data are collected for various purposes using various scopes, frequencies, definitions and classifications. Each type of data source is relevant to the analysis or monitoring of specific themes.

Figure A1.1
An information pyramid



A1.3. The role of accounting frameworks (which constitute the next tier of the pyramid) is to integrate those data so as to provide a single best picture of a broad concept or set of concepts, for example, economic growth or ecosystem condition. The compiler of accounts must therefore reconcile and merge data from various sources, taking into account differences in scope, frequency, definition and classification, as appropriate.

A1.4. Once the data have been integrated within a single framework, indicators can be derived that provide insights into the changes in composition or structure of the concept under measurement, changes in relationships between stocks and flows, and other features, taking advantage of underlying relationships within the accounts between, for example, stocks and flows, between capital and labour, and between production and consumption. Indicators such as GDP, national saving, national wealth, terms of trade and multifactor productivity all emerge from a single national accounts framework.

A1.5. The following subsections focus on the approach taken by national accountants to create the single best picture.

Key features of a national accounting approach

A1.6. Those unfamiliar with the way in which national accountants work through measurement issues need to acquire an understanding of two key factors. First, application of national accounting approaches generally commences with data from multiple sources that have already been collected. National accounting is therefore not focused on collecting and processing data or, for example, designing survey questions or determining sample sizes. It is assumed that those important tasks will have been completed by experts in specific subject areas, relevant methodologists and those in charge of administrative data. While, ideally, there will be a close relationship between the compilers of national accounts and those collecting the data, such a relationship can take time to evolve. In any event, the national accountant always remains one step removed from the collection and processing of the source data.

A1.7. Second, national accountants work "from the outside in", which is the result partly of the fact that they do not collect data. More largely, that can be attributed to the underpinning conceptual framework. National accounting is not a "bottom up" measurement approach through which aggregates are formed by summing available data. Rather, most effort is channelled into ensuring that the estimates that are compiled appropriately reflect the target concept, for example, economic growth, fixed capital formation or household consumption. Since, in general, no single data source can fully encompass a given concept, it is the role of the national accountant to ensure that the estimates reflect the concept as optimally as possible through melding, integrating and otherwise combining data from multiple sources.

A1.8. Further, as regards the second point, it is not sufficient to obtain the best estimate of each concept in isolation. Rather, the measurement of each concept must be considered within the context of the measurement of other concepts, following national accounts identities. Thus, for example, total supply and total use of each product must align. While the ultimate goal is to produce, at a single point in time, the single best picture of the concepts in scope of the national accounts framework, that cannot be achieved through reliance on a bottom-up strategy in which the micro neatly builds towards the macro. Instead, a top-down approach, or one that works from the outside in, must be applied.

A1.9. Building on those two key factors requires the consideration of the following related national accounting compilation principles:

(a) The maintenance of time series is fundamental. Perhaps the most important principle is that in creating the single best picture, it is not sufficient for each data point to stand alone in time, that is, changes over time must be regarded as part of the picture. Often, national accounts time series extend for over 30 or 40 years, and there are few, if any, data sources that are maintained consistently over such time frames. Indeed, data sources generally improve their methods and coverage over time. Consequently, a key task in national accounting is to link information from various sources and over time, and hence various methods may be applied to measure the same concept consistently;

(b) Prices, quantities (volumes) and values are all relevant. While the vast bulk of the relationships in the national accounts framework are presented in value terms, that is, in terms of the actual monetary amounts transacted, the most significant proportion of the resources for compiling national accounts are targeted at decomposing the changes in value into changes in prices or changes in underlying volumes. Generally, most analyses in the national accounts—for example, of growth rates, productivity and investment—are conducted in volume terms, that is, after removing price effects. Again, achieving the single-best-picture goal requires harmonizing those different perspectives at the component and aggregate levels;

(c) There is a need for revisions. Without a time constraint on the integration of data and the release of results, it is likely that national accounts would never be completed. Given their scope, there is always new information that may be considered or new methods that may be adopted to refine the single best picture. National accounting thus operates by ensuring the release of the best picture at regular intervals, with the knowledge that it will be revised in due course when additional information becomes available;

(d) Accounting is iterative. The process of integrating data for accounting is fundamentally not a single, one-off process. Each time a set of accounts is compiled, various integration issues will arise, which in general will be resolved only through attempts at integration, achieving an understanding of the reasons for imbalances, and implementation of possible solutions. A single best picture will emerge gradually; and, ideally, resolving these integration issues will be a task that involves both accountants and areas of data supply. Such joint resolution is an important factor in the mainstreaming of various data to obtain an overall picture.

A1.10. One overarching consequence of the adoption of a national accounting approach to compilation is that comparability of various estimates is not assessed primarily on the basis of method. Instead, comparability is based primarily on the extent to which different estimates accurately reflect the target concept. Indeed, since each national accountant needs to integrate different source data, it is likely that a focus on comparability of methods will not be a helpful starting point. At the same time, it must be accepted that all methods do not produce estimates of equal quality.

A1.11. One benefit of a concentration on concepts is that countries tends to focus their resources on measuring those areas within the accounting framework that are of most relevance to them. For example, in a country where agriculture is a dominant activity, resources should be allocated to its measurement. In a country with a different economic structure—one, for example, with a large financial sector—the balance of resources and the choice of data and methods would—and should—be different. Since economic structures change over time, methods also need to adapt. The development of services statistics and associated measurement methods over the past 25 years is a good example of the evolution of compilation approaches even as the underlying concepts remain stable.

Applying the national accounting approach to ecosystem accounting

A1.12. The goal in most cases, including with respect to the data sets that underpin ecosystem accounting, is to generate databases pertaining to a single theme or topic and to provide the best estimates based on the methods selected and the resources available. While this may very well—or should—involve, as part of the process of editing the data set, comparison with other data sets, it generally does not involve full integration and reconciliation with other data sets.

A1.13. A national accountant, on the other hand, is not compiling such a data set but, rather, is seeking to undertake such integration. In many contexts, that is an activity that must, at some point, be undertaken by a data user, analyst or decision maker. That is to say, at some point, interpretations or judgments would need to be brought to bear on data from different sources that may suggest different trends. Within the scope of macroeconomic analysis, national accountants, acting with the rigour demanded by the national accounting framework, make such judgments regarding relative data quality. The alternative would be a situation where economic analysts might base their judgments on varying definitions of economic aggregates and of measurement scope.

A1.14. Through the application of a national accounting compilation approach within ecosystem accounting, that approach is extended to biophysical and scientific data. That is, within ecosystem accounting, the goal is to integrate the various sources of information on ecosystem condition, ecosystem services, and economic production and consumption so as to generate the single best picture.

A1.15. Consequently, for the purposes of ecosystem accounting, it is necessary but not sufficient to possess data for a particular ecosystem type or for a selected set of ecosystem services. Indeed, efforts must be directed towards obtaining information that permits assessment of the entire area of interest and the full scope of supply of ecosystem services. While it is certainly justifiable to channel most resources into measuring the ecosystems and the ecosystem services that are considered most relevant and most significant, that should not distract from the striving to measure the whole.

A1.16. Putting together national accounts-based estimates entails the adjustment of data that are regarded as being of good quality so as to ensure an integrated picture. And since the emphasis is on the measurement of a defined framework, some data sources, whatever their quality, may not be used if they are not defined in accordance with the required concepts.

A1.17. While those remarks may appear somewhat dogmatic, in practice a national accounts approach reflects a strong reluctance to neglect any type of pertinent information. Indeed, efforts are generally made to examine all relevant data and, where necessary, concepts undergo adjustments so as to permit integration.

A1.18. In the area of ecosystem accounting, work is ongoing on defining the final integrated framework. There remains considerable scope in this regard for an active dialogue between those managing the underlying data sets and those designing the ecosystem accounting framework. That dialogue is essential for the generation of high-quality information.

Principles and tools of national accounting

A1.19. The focus of this section is to provide a brief description of the main principles and tools applied by national accountants to ensure a coherent integration of data from multiple sources. An extensive discussion of those principles is contained in the 2008 SNA (European Commission, IMF, OECD, United Nations and World Bank, 2009) and an extended overview is provided in SEEA Central Framework.

A1.20. *Accounting identities*. The accounting system relies on a number of identities, that is, expressions of relationships between different variables. Two of those relationships are of particular importance in ecosystem accounting. The first is the supply and use identity, according to which the supply of a product, or, in this case, an ecosystem service, must balance the use of that product. As information on the supply and use of a product is often derived from multiple sources, that identity—which applies in both physical and monetary terms—provides a means of reconciling data.

A1.21. According to the second identity, which encapsulates the relationship between balance sheets and changes in assets, the opening stock plus additions to stock less reductions in stock must equal the closing stock. Like the supply and use identity, that identity applies in both physical and monetary terms. Without the need to conform to that identity, there would be no requirement to ensure that observed changes in ecosystem assets (e.g., occurring through natural growth or extraction) were aligned with the series of point-in-time estimates of ecosystem condition that underpin the balance sheets.

A1.22. *Frequency of recording*. In order for a single best picture to be provided across multiple data sources, it is essential that there be a common reference point, which is referred to in accounting terms as the accounting period. Generally, it is recommended that the accounting period used across a set of SEEA-based accounts be one year, as that supports alignment with underlying economic data that are usually compiled based on that periodicity. Flows are measured so as to ensure that all activity occurring during the selected accounting period is recorded. Stocks are measured at the opening and closing dates of the accounting period.

A1.23. As it is common for different data sources to be associated with different reference periods, adjustments are required to ensure an appropriate integration. For example, flows may be covered by a period that is not aligned with the selected accounting period, and/or stock information may not be linked to the opening date of the period and/or to its closing date . In cases in which there are adjustments, they should be made explicit; and if no adjustments are made, then the underlying assumptions in this regard should be clearly defined.

A1.24. For the measurement of some ecosystem characteristics and services the use of an annual frequency may not be ideal. For example, at larger scales, changes in ecosystem extent may be detectable only over periods of three to five years. By contrast, in measurement of changes in water resources, sub-annual data may be required for the detection of seasonal variation. Those alternative frequencies should be used, as relevant and as appropriate, to record and present specific data, with a view to ensuring that decision-making and analysis are supported in the best way possible. At the same time, a single frequency is required for the integration of all data, including economic data, and it is for such a purpose that annual recording is proposed. That frequency also ensures a regular presentation of ecosystem accounting data to decision makers and supports the mainstreaming of environmental information, which is a core goal of SEEA.

A1.25. In addition to those key principles, there are a few common tools and methods that are applied in national accounting, as outlined in the following paragraphs.

A1.26. *Benchmarking, interpolation and extrapolation*. Along the range of different data sources, there is usually one that is of particularly high quality with respect to coverage and scope. Commonly, such a source provides a benchmark estimate at a point in time or for a given accounting period. It is then typical to employ indicators, using this information as a base, both for: (a) the extrapolation of that information so as to obtain estimates that are more up to date, through a process known as "nowcasting"; and (b) the interpolation between benchmarks, for example, in cases in which the best data are collected every three years but annual estimates are required for accounting purposes. Generally, those techniques are applied to generate the initial estimates for a particular variable and may be subsequently adjusted through the balancing and integration process.

A1.27. In some respects, those types of benchmarking and interpolation/extrapolation techniques may be regarded as a form of modelling. However, the extent to which that is the case depends on the sophistication of the technique that is used. Generally, regressions and similar approaches are not utilized, since maintaining those models over the full extent of a national accounts framework would be highly resource-intensive. Further, since the estimates for an individual time series are eventually integrated within a series of accounting identities, it may be difficult to rationalize the statistical advantage of applying detailed modelling approaches for individual series.

A1.28. *Modelling*. Modelling does become more significant when there is a clear shortage of data for particular variables, that is, when there are no direct estimates or benchmarks that can provide a starting point. In such cases, modelling may be required. One example from the standard national accounts involves the estimation of consumption of fixed capital (depreciation). That is commonly derived through use of the so-called perpetual inventory model (PIM), which requires estimates of capital formation and assumptions regarding asset lives and depreciation rates.

A1.29. Within the context of ecosystem accounting, the spatial detail required is likely to increase the need for modelling considerably—a situation that will represent uncharted territory for many national accountants. The *Technical Recommendations* consider the role of biophysical modelling in ecosystem accounting, as well as the general issue of spatial imputation where information estimated in one location is applied in others (see chap.V). Such modelling and imputation may be relevant in the measurement of ecosystem extent, ecosystem condition and ecosystem services. While those may not be traditional "sources" of information for national accounts-type work, there is no particular reason why such modelled data cannot be directly incorporated. It remains the task of accountants to integrate all available data as best as they can. At the same time, a balance must be struck with respect to the proportion of data that are modelled within the overall data set, since excessive reliance on modelled rather than directly collected data may raise questions regarding, for example, the accuracy of the information.

A1.30. A general issue that is of relevance at every point in this discussion is that of data quality. For the national accounts, in contrast with many of the source data that feed into them, it is usually impossible to generate a precise estimate of common measures of data quality such as standard errors. The melding and synthesis of multiple data sources render that a relatively intractable task. Along the same lines, assessing the impact of the application of accounting principles on data quality poses a challenge. While it is clear that the application of those principles conduces to coherence of the final data, it is often unclear how much adjustment may have been required to ensure that coherence.

A1.31. It is often the case that accounts are ultimately deemed of relatively good quality if the picture they present is broadly considered to be a reasonably accurate one. That may be determined based on:

- How well the accounts incorporate data that are regarded as of high quality;
- Commentary by accountants on the extent of adjustment required. In that regard, accounts may be left unbalanced in a number of situations, and the size of the discrepancy may be a measure of quality;
- The size of revisions to the estimates. In that regard, a consistent pattern of large revisions, either up or down, to initial estimates would reflect the relative quality of the source and methods;
- The usefulness of the accounts data to users. If at the end of the day, those data do not support meaningful decision-making or analysis, then the quality of the accounts must be questioned.

A1.32. The treatment of uncertainty in accounting contexts constitutes a final area of concern. SEEA EEA provides an overview of several uncertainty-related factors that may affect the information used in ecosystem accounting (see chap. V). By its very nature, accounting aims at providing a single best picture and, in that context, it seems to ignore issues of uncertainty. Three points should be noted. First, data sources used in an accounting exercise are subject to statistical error, and that should be taken into consideration in the compilation of the accounts themselves. Ideally, the levels of concern regarding the data would be described in the reporting of accounting outputs. The same holds true for any assumptions that are applied in the construction of accounting estimates—applied, for example, in estimating future flows of ecosystem services in net present value calculations.

A1.33. Second, it would be feasible—although that is not generally undertaken—to consider publication of some ecosystem accounting aggregates within sensitivity bounds. The challenge of course is to ensure that a meaningful balance among the accounting identities was maintained. That being the case, further consideration of how uncertainty can be usefully reflected within an accounting context will be needed.

A1.34. Third, accounting does not provide a model for forecasting future changes in systems. While the national accounts organize information on the composition of and changes in economic activity, they do not purport to provide future estimates of economic growth. It is economic models instead that perform that role, generally through use of time series of national accounts data.

A1.35. Moreover, ecosystem accounting is not designed to provide a model of ecosystem behaviour that can be used to forecast ecological outcomes. It records, ex post, measures of changes in ecosystem condition and flows of ecosystem services. How that information might be combined to support estimates of future flows or changes in condition is a separate issue and is likely subject to considerable uncertainties. The distinction between creating a structured information set and modelling future states is not often made in scientific discourse and is usually overlooked by economists. That distinction is fundamental, however, to understanding the role that accounting may be able to play in supporting the mainstreaming of environmental information into decision-making.

A1.36. The use of the national accounts—inappropriately—as a forecasting model must be distinguished from the use of future data in the derivation of some national accounting estimates. One particularly relevant case concerns the use of information on future flows of services in the measurement of ecosystem capacity and ecosystem asset net present values. In that regard, the information on future flows required for the measurement of net present values should ideally be obtained from specific data sources or derived from (biophysical) models or expert opinion. Where such inputs are not available, national accountants commonly make assumptions regarding future flows (usually based on history) so that a net present value can be estimated. That, however, is by no means meant to suggest that the national accounts framework constitutes a model that can be applied to forecasting.

Annex II
Overview of various natural capital accounting initiatives

Introduction

A2.1. The present annex provides an overview of SEEA-based ecosystem accounting projects and initiatives worldwide. As many of them are at relatively early stages, their inclusion in this overview is intended to provide an indication of both: (a) the level of interest that has been generated in ecosystem accounting since its endorsement by the Statistical Commission in 2013;[55] and (b) the potential for work to be undertaken in a wide range of countries and contexts.

A2.2. The content of this overview is not intended to be exhaustive, nor is the presentation of each project sufficiently detailed to facilitate a full understanding of the progress that has been made or the methods and data that will be or have been used. Nonetheless, it does provide a useful introduction to ecosystem accounting for those countries and agencies interested in commencing work in that area.

A2.3. Given the pace of advancement in ecosystem accounting, the content of this overview will not be current for any length of time. Consequently, it is highly recommended that those interested in building a more detailed understanding of SEEA-based ecosystem accounting projects refer to the latest information on the website of the Statistics Division of the Department of Economic and Social Affairs of the United Nations.[56] The Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Knowledge Center website[57] provides links to relevant ecosystem accounting projects and reports.

[55] See *Official Records of the Economic and Social Council, 2013, Supplement No. 4* (E/2013/24), chap. I, sect. C, decision 44/104.

[56] See https://seea.un.org

[57] See www.wavespartnership.org/knowledge-center.

Brief overview of countries and organizations that have implemented ecosystem accounting initiatives

A2.4. Table A2.1 lists the countries and agencies that have implemented SEEA-based ecosystem accounting programmes as of December 2017. The listing is based on responses to a Statistics Division survey on the implementation of SEEA, which was completed at the end of October 2017, and information on other projects provided by members of the Technical Committee on SEEA EEA. While there is also extensive research being undertaken in various parts of the academic community, that work is not within scope of the present annex.

A2.5. The list is not intended to be exhaustive, although it does highlight the broad sweep of project coverage around the world. Further, it should be apparent from the entries on the list that many of the initiatives are led not by national statistical offices but rather by other government agencies, subnational levels of government, and/or non-government organizations. The common feature uniting those projects is their use of SEEA.

Table A2.1
SEEA EEA-based ecosystem accounting activities

Countries with activities at national or subnational level
Australia (Australian Bureau of Statistics, Commonwealth Department of Environment and Energy and State Department of the Environment)
Belgium (Research Institute for Nature and Forest (INBO), Flemish Institute for Technological Research (VITO))
Canada (Statistics Canada)
Colombia (National Statistical Office)
Denmark (National Statistical Office)
Finland (Finnish Environment Institute (SYKE), Statistics Finland)
Indonesia (Statistics Indonesia (BPS))
Liberia (Conservation International)
Mauritius (Statistical Office)
Mexico (National Institute of Statistics and Geography (INEGI))
Netherlands (Statistics Netherlands, Wageningen University)
Norway (Norwegian Institute for Nature Research (NINA), Statistics Norway)
Peru (Conservation International)
Philippines (Philippine Statistics Authority (PSA), National Economic and Development Authority (NEDA), Department of Environment and Natural Resources (DENR))
Rwanda (Rwanda Natural Resources Authority (RNRA), World Bank, Science for Nature and People Partnership (SNAPP))
South Africa (Statistics South Africa, South African National Biodiversity Institute (SANBI))
Spain (Institute for Public Goods and Policies (IPP), Spanish National Research Council (CSIC))
Sweden (National Statistical Office)
Uganda (National Planning Authority (NPA), National Environment Management Authority (NEMA), UNEP-WCMC)
United Kingdom of Great Britain and Northern Ireland (Department for Environment, Food and Rural Affairs (DEFRA), Office for National Statistics (ONS))
United States of America (United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), United States Environmental Protection Agency (EPA), Bureau of Economic Analysis of the United States Department of Commerce (BEA))

International ecosystem accounting programmes and participating entities
Advancing National Capital Accounting (ANCA)—Statistics Division, Department of Economic and Social Affairs, United Nations; Secretariat of the Convention on Biological Diversity, United Nations Environment Programme (UNEP) (2013–2016): (Bhutan, Chile, Indonesia, Mauritius, Mexico, South Africa, Viet Nam)
Knowledge Innovation Project on an Integrated System for Natural Capital and Ecosystem Services Accounting in the European Union (KIP-INCA)—Eurostat, European Union Joint Research Centre, Directorates-General for Environment and for Research and Innovation, European Commission, and European Environment Agency (2015–2020); (European-Union and several member States of the European Union)
Natural Capital Accounting and Valuation of Ecosystem Services project—Statistics Division, UNEP, secretariat of the Convention on Biological Diversity and European Union, funded by European Union (2016–2019); (Brazil, China, India, Mexico, South Africa)
Wealth Accounting and the Valuation of Ecosystem Services (WAVES) partnership—World Bank (2010 onward); (Botswana, Colombia, Costa Rica, Guatemala, Indonesia, Madagascar, Philippines, Rwanda)

A2.6. The list does not reflect an effort to separately identify cases where multiple projects are under way in the same country. Further, there are a number of countries whose projects are currently focused on individual regions within the country rather than the national level. It is also to be noted that the specific types of ecosystem accounts that are being developed vary from project to project. Those range from ecosystem extent and condition accounts to ecosystem services accounts and valuation.

A2.7. Moreover, the list does not include a wide range of projects that may provide input to, or could be associated with, the implementation of SEEA-based ecosystem accounting. There are many such projects, focusing, for example, on the development of Earth observation data, the measurement of biodiversity and ecosystem condition, and the valuation of ecosystem services.

Descriptions of selected ecosystem accounting activities

Australia

A2.8. In Australia, a number of organizations have used the SEEA EEA framework to develop ecosystem accounts for different purposes across different regions at different scales and within different time frames. Some recent examples include the Australian Bureau of Statistics: Experimental Environmental-Economic Accounts for the Great Barrier Reef, 2017[58], which cover both the marine and terrestrial environments of the region, including information on a selection of ecosystem services and natural capital; the Government of the State of Victoria, which has integrated environmental-economic accounting into government reporting, programme evaluation and decision-making and produced the Marine and Coastal Ecosystem Accounts for Port Phillip Bay, 2016[59], Valuing Victoria's Parks, 2015[60] and Victorian Experimental Ecosystem Accounts, 2013 which all feature ecosystem accounting; the Office of the Australian Capital Territory (ACT) Commissioner for Sustainability and the Environment, which has developed a pilot set of environmental-economic accounts for the ACT[61] based on the SEEA framework, including ecosystem accounts; and the Australian National University Fenner School of Environment and Society, whose researchers produced a set of experimental ecosystem accounts for the Central Highlands of Victoria[62] under the National Environmental Science Programme, which enabled an assessment of the use and economic contribution of ecosystem assets from the region and a discussion of implications for alternative activities.

A2.9. At a meeting in late 2016, Australia's environment ministers, representing all nine federal and state jurisdictions, agreed to advance a strategy for the implementation of SEEA accounts across Australia using a national approach and with a focus on the development of ecosystem accounts. In December 2017, a broad strategy for the following five years was agreed upon, and appropriate resourcing was identified; and in 2018, a detailed action plan will be established, which will take advantage of the substantive advances being made in other countries.

Canada

A2.10. In 2011, Statistics Canada received funding for a three-year interdepartmental project entitled "Measuring ecosystem goods and services". The purpose of the project was to conduct research on the development of ecosystem accounts, indicators and valuation techniques. The results were released in the annual publication *Human Activity and the Environment*, in the 2013 issue, entitled "Measuring ecosystem goods

58 See www.abs.gov.au/ausstats%5Cabs@.nsf/0/021873EB0FFA07A9CA2581820077EE15?Opendocument.

59 See www.environment.vic.gov.au/__data/assets/pdf_file/0025/49813/Marine-and-Coastal-Ecosystem-Accounting-Port-Phillip-Bay.pdf.

60 See www.forestsandreserves.vic.gov.au/media-releases/valuing-victorias-parks.

61 See www.environment-commissioner.act.gov.au/publications/environmental-economic-accounts.

62 See https://tsrhub.worldsecuresystems.com/Ecosystem%20Complete%20Report_V5_highest%20quality.pdf.

and services".[63] That work led to increased efforts in the area of ecosystem accounting. For example, initial ecosystem account tables were created for Canada's largest metropolitan areas and published in 2016 in *Human Activity and the Environment 2015*, entitled "The changing landscape of Canadian metropolitan areas".[64] In 2017, Statistics Canada released asset, supply and use accounts for freshwater, in the 2016 issue of *Human Activity and the Environment*, entitled "Freshwater in Canada",[65] which also provides maps and data tables, by drainage region, on some of the drivers of change that influence water provisioning and freshwater quality, including population, land-cover change, and nutrient residuals and emissions. Work is ongoing to update and augment those accounts on a regular basis.

Indonesia

A2.11. In 2016, Statistics Indonesia began testing SEEA EEA approach, including development of a land account, in collaboration with the Ministry of Environment and Forestry and other government agencies and supported by the WAVES programme, for all regions, as well as at the national scale. An ecosystem extent account for Sumatera and Kalimantan, and a water account for a major watershed in Java, were scheduled for release in 2018. A pilot account for peatlands is also being discussed with the government agencies responsible for managing resources in Indonesia's peatlands, especially in Sumatera, Kalimantan and the Papua islands. Currently, work is in progress, with, as a first output, a draft land account for all land types, which is being sent to various stakeholders for review.

Mexico

A2.12. Building on a long history of environmental-economic accounting, Mexico was one of seven pilot countries in the Advancing Natural Capital Accounting (ANCA) project jointly launched by the Statistics Division, the UNEP TEEB Office and the Secretariat of the Convention on Biological Diversity, with funds provided by the Norwegian Agency for Development Cooperation (NORAD). During the two-year period of implementation of the project, an inter-institutional technical working group was established, national technical capacities for compiling experimental ecosystem accounts were developed, and a small pilot study was completed. The pilot study compiled extent accounts for 2002 and 2011 for the State of Aguascalientes, evaluated the changes in ecosystem extent between 2002 and 2011, and compiled condition accounts for soil erosion, biodiversity, water supply and soil carbon content.

A2.13. In 2017, Mexico was again included as a pilot country in the European Union-funded project whose aim was to further test ecosystem accounting; Brazil, China, India and South Africa were also included. Additional pilot studies will be conducted to evaluate (in physical and, whenever possible, monetary terms) important ecosystem services of particular interest at the national, state or site level.

Netherlands

A2.14. In 2016, Statistics Netherlands and Wageningen University commenced work on a three-year project entitled "Ecosystem accounting for the Netherlands", funded by the Dutch Ministries of Economic Affairs, and Infrastructure and the Environment. The aim of the project is to test and implement SEEA EEA ecosystem accounting for the Netherlands. The decision was made to develop the core accounts and include carbon and biodiversity as thematic accounts. The focus of the set of accounts is largely

[63] See www.statcan.gc.ca/pub/16-201-x/2013000/after-toc-aprestdm1-eng.htm.

[64] See www.statcan.gc.ca/pub/16-201-x/16-201-x2016000-eng.htm.

[65] See www150.statcan.gc.ca/n1/pub/16-201-x/2017000/sec-1-eng.htm

on terrestrial ecosystems. A comprehensive carbon account has been released[66] and an ecosystem unit map has been compiled for reference years 2006 and 2013.[67]

A2.15. The biophysical ecosystem service supply and use account for the Netherlands was one of the core accounts that were developed. High-resolution spatial models were constructed for a broad range of ecosystem services. Thirteen ecosystem services were modelled, including five provisioning services, six regulating services and two cultural services. Those ecosystem services were analysed and maps were produced. Based on the results obtained with the spatial models, biophysical supply tables were developed and analysed. The ecosystem services supply tables were developed for ecosystem types and for the Netherlands provinces. Use tables have been created for the various economic sectors that would benefit from the ecosystem services. Valuation of ecosystem services and the development of ecosystem condition accounts are now under development.

66 See www.cbs.nl/-/media/_pdf/2017/45/carbon-account-2017.pdf.

67 See www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map.

Philippines[68]

A2.16. From 2014 to April 2017, the Government of the Philippines tested the SEEA EEA approach at local levels for pilot provinces and areas in Palawan, Laguna and Quezon provinces. Pilot studies on SEEA EEA accounts were developed in two areas, namely, Southern Palawan and Laguna de Bay. The pilot accounts comprised land accounts, condition accounts, and ecosystem services supply and use accounts for both areas. In addition, a water account was developed for Laguna de Bay and a carbon account was compiled for Southern Palawan. Another pilot study entailed the development of a mangrove ecosystem account, specifically designed for the pilot province, Quezon, in Pagbilao (region IV-A). The mangrove account focused on: (a) area; (b) biomass; (c) carbon stock; and (d) carbon sequestration.

A2.17. As the country's compiler of environmental and natural resource accounts, the Philippine Statistics Authority (PSA)—through the Environment and Natural Resources Accounts Division (ENRAD) under the Macroeconomic Accounts Service—has collaborated with other government agencies in the pilot studies. The pilot studies in Palawan and Laguna provinces were carried out jointly through the Department of Environment and Natural Resources (DENR) and its various bureaux and departments, including the Forest Management Bureau and its regional offices. The Palawan Council for Sustainable Development and the Laguna Lake Development Authority, both under DENR, served as the lead departments for the development of the two ecosystem accounts for Southern Palawan and Laguna de Bay. The national mapping agency (NAMRIA) was responsible for preparing the national-scale extent account, jointly with PSA. Various other departments provided data and supported development of the accounts. On the basis of the accounts, a set of 10 policy briefs on specific policy-relevant topics were prepared.

68 For further information, see www.wavespartnership.org/en/philippines.

Rwanda[69]

A2.18. In Rwanda, initial national ecosystem accounts were developed with support from the Science for Nature and People Partnership (SNAPP), which includes the Nature Conservancy, the Wildlife Conservation Society and the National Centre for Ecological Analysis and Synthesis (NCEAS) at the University of California at Santa Barbara. The Rwanda ecosystem accounts, which are based on data for the period between 1990 and 2015, quantify changes in carbon storage, in sediment retention and loss, and in water quantity (through measurement of the size of river flows in the wet

69 For further information, see www.wavespartnership.org/en/rwanda.

and dry seasons). The accounts highlight specifically the changes in water quantity, water quality, hydroelectric power generation, irrigation and domestic water supply.

A2.19. The ecosystem accounts will inform the development of the country's third Economic Development and Poverty Reduction Strategy. Furthermore, with support from the WAVES partnership and the intergovernmental Regional Centre for Mapping of Resources for Development (RCMRD), the Rwanda Natural Resources Authority developed a 2015 land-cover map that enables ecosystem accounts to be directly compared with land-use accounts (Rwanda began tracking land use in 2014). Development of the 2015 map included extensive capacity-building work carried out by the Rwanda Natural Resources Authority and field validation of images processed from satellite data.

South Africa

A2.20. During 2014 and 2015, South Africa was one of seven pilot countries involved in the Advancing Natural Capital Accounting project (ANCA), led by the Statistics Division in partnership with the United Nations Environment Programme (UNEP) and the secretariat of the Convention on Biological Diversity, with funding from the Government of Norway. That project enabled the development of two sets of pilot ecosystem accounts: national river ecosystem accounts (covering extent and condition of river ecosystems), and land and ecosystem accounts for the province of KwaZulu-Natal. Building on those pilot accounts, South Africa is now participating as one of five countries in the European Union-funded Natural Capital Accounting and Valuation of Ecosystem Services project, led by the Statistics Division and UNEP. The programme of work for the project is likely to include national land and ecosystem accounts, and a full suite of ecosystem accounts for the province of KwaZulu-Natal. It may also include other experimental accounts, for example, accounts for protected areas and species of special concern. In addition, a national strategy for ecosystem accounting will be developed.

A2.21. Ecosystem accounting is led by Statistics South Africa, the national statistics office, and the South African National Biodiversity Institute (SANBI), an organ of State falling under the authority of the Department of Environmental Affairs, which exercises the mandate for monitoring and reporting on the state of the country's ecosystems. It is intended that ecosystem accounts will provide detailed spatial information on ecosystems that can be used to inform national planning, within the context, for example, of the National Spatial Development Framework, including municipal land-use planning, as well as ecosystem restoration priorities.

United Kingdom of Great Britain and Northern Ireland

A2.22. The United Kingdom ecosystem accounts have been developed by integrating bottom-up, spatially disaggregated modelling approaches with data at a national (top-down, aggregate) level. That has enabled a time series of high-level accounts for various broad habitats to be compiled in a way that is consistent and hence additive, facilitating the provision of information on a wide range of different assets and services in both physical and monetary terms. Although a few initial accounts have been produced for certain subnational areas such as national parks, there has not yet been an attempt to disaggregate the top-down estimates to more spatially detailed areas, as research to date has shown that such disaggregations are not robust.

A2.23. At the national level, accounts, including a full sequence for woodlands, farmland and freshwater habitats, among others—covering extent, condition, service flows in physical and monetary terms, and monetary asset values—have already been developed. Initial, more exploratory accounts have been produced for marine areas, coastal margins, and mountains, moorlands and heathland. A separate ecosystem account for urban areas in the United Kingdom has also been developed, which incorporates valuations of a range of services more relevant to urban residents, such as noise mitigation, local climate control, air filtration and support for physical health. These are in addition to the more mainstream valuations of provisioning services, carbon sequestration and recreation.

A2.24. Although the United Kingdom accounts are still categorized as experimental, they are already generating valuable insights regarding how different habitats provide different services and the relative importance of those services. The results are widely referenced by the Government and other entities, and the use of those accounts is expected to increase as they become more established.

A2.25. More details on the results and methodologies used can be found at the Natural Capital Accounts webpage on the United Kingdom Office for National Statistics website.[70]

[70] See www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/naturalcapital.

United States of America

A2.26. In late 2016, the United States Geological Survey (USGS) began coordinating its work with that of other United States agencies, international agencies, academics, private industry representatives, and natural capital accounting (NCA) practitioners from other countries, with a view to demonstrating, by 2019, that natural capital accounting is feasible within the United States.[71] Pioneering work undertaken elsewhere on the development and application of SEEA EEA, and a relatively rich supply of national and subnational data, ecosystem services and modelling expertise, and computational resources, were determined to be the elements whose contribution would be essential in making a rapid demonstration of that type possible.

[71] See https://powellcenter.usgs.gov/view-project/57741607e4b07657d1a9910c.

A2.27. Within the timeline, elements of a national-level accounting structure are being proposed, together with at least one subnational scale application, starting in a 10-State region of the south-eastern United States. Work to date has focused on land and water accounts, following SEEA Central Framework, which provide a context for changes observed in the ecosystem accounts. The USGS-led group aims at integrating national-scale biophysical models of ecosystem services using semantic models on the cloud. Once the initial modelling design is operational, that approach, as compared with one that entails a new chain of model building and data matching for each iteration of an ecosystem account, will reduce the time and resources needed for all subsequent modelling runs, ensuring greater flexibility and reliability at lower cost.

Knowledge Innovation Project on an Integrated System for Natural Capital and Ecosystem Services Accounting in the European Union (KIP-INCA)

A2.28. The European Union, in the Seventh Environment Action Programme and the European Union Biodiversity Strategy to 2020, has set itself ambitious targets for the preservation and better management of natural capital. A shared Knowledge Innovation Project was established at European Union level to develop an Integrated System for Natural Capital and Ecosystem Services Accounting (KIP-INCA) as a means of building on the knowledge base for achieving these objectives. The organizations taking KIP-INCA forward are Eurostat, the European Union Joint Research Centre, the Directorate-General for Environment and the Directorate-General for Research and Innovation of the European Commission, and the European Environment Agency.

KIP-INCA builds on the first phase of the European Union initiative on Mapping and Assessment of Ecosystems and Services (MAES), whose aim is to map and assess ecosystems and their services in the European Union. It also supports the second phase of MAES, whose aim is to value ecosystem services and integrate them into accounting and reporting systems by 2020.

A2.29. SEEA EEA provides the methodological starting point of KIP-INCA. The KIP-INCA project aims towards developing accounts on the extent and condition of ecosystems present in the European Union, as well as accounts for selected ecosystem services from these ecosystems and their contribution to the economy and human well-being. The project began in 2015 and will run until 2020. Key results of phase 1 of the project and a road map for objectives to be completed by 2020 can be found in the report on phase 1 of KIP-INCA.[72]

Food and Agriculture Organization of the United Nations (FAO)

A2.30. FAO has developed the System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries (SEEA-AFF), which applies the environmental economic structures and principles set out in SEEA Central Framework to the activities of agriculture, forestry and fisheries. SEEA-AFF has recently been implemented in Australia.[73]

A2.31. Moreover, FAO has begun collaborating with the Joint Research Centre on the development of provisioning ecosystem services accounting which starts from SEEA-AFF and is consistent with SEEA EEA.

A2.32. Further, work on the linkages and overlaps between SEEA Central Framework and SEEA EEA for carbon accounting lies within the scope of the collaboration between FAO and Statistics Netherlands that is in place.

World Bank - Wealth Accounting and the Valuation of Ecosystem Services (WAVES) partnership

A2.33. The World Bank promotes SEEA implementation through the Wealth Accounting and the Valuation of Ecosystem Services (WAVES) global partnership.[74] WAVES focuses on policy uptake and the institutionalization of natural capital accounts using the SEEA methodology.[75] From the WAVES standpoint, the SEEA EEA framework has been instrumental in enabling the move towards an international statistical standard for ecosystem accounting.[76] Through WAVES, the World Bank has supported several countries in advancing efforts towards ecosystem accounting (see table A2.2), with particular progress having been made by the Philippines and Rwanda. At the regional level, WAVES has supported communities of practice in developing ecosystem accounts, and has also facilitated South-South learning. At the global level, WAVES has worked on transitioning ecosystem accounting towards an accepted international standard, making use of Earth observation data and better methodology for the valuation of ecosystem services.[77]

[72] See http://ec.europa.eu/environment/nature/capital_accounting/pdf/KIP_INCA_final_report_phase-1.pdf.

[73] See www.abs.gov.au/ausstats/abs@.nsf/mf/4632.0.55.001.

[74] For further information, see www.wavespartnership.org/en.

[75] See, for example, *Forum on Natural Capital Accounting for Better Policy Decisions: Taking Stock and Moving Forward* (Vardon and others, 2017). Available at www.wavespartnership.org/en/knowledge-center/forum-natural-capital-accounting-better-policy-decisions-taking-stock-and-moving.

[76] See, for example, Forest Accounting Sourcebook: Policy Applications and Basic Implementation (Castañeda and others, 2017), available at www.wavespartnership.org/en/knowledge-center/forest-accounting-sourcebook; and Managing Coasts with Natural Solutions (Beck and Lange, eds., 2016), available at www.wavespartnership.org/en/knowledge-center/managing-coasts-natural-solutions.

[77] See "Prices for ecosystem accounting" (Atkinson and Obst, 2017). Available at www.wavespartnership.org/en/knowledge-center/prices-ecosystem-accounting-draft-1.

Table A2.2
Progress on ecosystem account components in WAVES countries (as of 31 March 2017)

	Ecosystem extent	Ecosystem condition	Physical supply and use	Monetary supply and use
Colombia	▲△	▲	▲△	▲△
Costa Rica	●		○	○
Guatemala	●		●	
Indonesia	△			
Philippines	▲○	▲○	▲○	▲○
Rwanda	●		○	

Key

● National scale, complete
○ National scale, in progress
▲ Subnational scale, complete
△ Subnational scale, in progress

Source: WAVES Annual Report 2017 (figure 2.1), available at www.wavespartnership.org.

Statistics Division, Department of Economic and Social Affairs: work programme and externally funded projects

A2.34. Under the auspices of the United Nations Committee of Experts on Environmental-Economic Accounting, the Statistics Division of the Department of Economic and Social Affairs supports the methodological development of SEEA EEA and the implementation of ecosystem accounting in countries through its regular work programme and externally funded projects, including the Norwegian Agency for Development Cooperation-funded Advancing Natural Capital Accounting (ANCA) project and the European Union-funded Natural Capital Accounting and Valuation of Ecosystem Services project.

(i) Advancing Natural Capital Accounting (ANCA) project

A2.35. The ANCA project, which was jointly implemented by UNEP, the Statistics Division and the Secretariat of the Convention on Biological Diversity and funded by the Norwegian Agency for Development Cooperation, supported the implementation of SEEA EEA in seven pilot countries: Bhutan, Chile, Indonesia, Mauritius, Mexico, South Africa and Viet Nam. The project began in December 2013 and was completed in December 2016.

A2.36. Through the project, national plans on advancing environmental-economic accounting were developed in the seven pilot countries. They outlined each country's plan for developing information in support of sustainable development and advancement of SEEA implementation. The national plans detail the policy situation in the country, institutional arrangements and the legal framework for statistics, as well as the data situation. The plans also identify ongoing country initiatives and highlight opportunities and risks associated with SEEA implementation in countries.[78]

A2.37. The project encompassed not only the development of national plans but also support for the piloting of two types of ecosystem accounts in South Africa: (a) national river ecosystem accounts for South Africa; and (b) land and ecosystem accounts for KwaZulu-Natal.[79] Pilot ecosystem accounts were also compiled in Mexico for Aguascalientes. A range of training materials on ecosystem accounting have been developed.

78 The national plans are accessible at www.teebweb.org/areas-of-work/advancing-natural-capital-accounting/.

79 Reports on the two pilot projects are accessible at www.teebweb.org/areas-of-work/advancing-natural-capital-accounting/.

(ii) Natural Capital Accounting and Valuation of Ecosystem Services project

A2.38. The National Capital Accounting and Valuation of Ecosystem Services project was implemented jointly by the Statistics Division, UNEP and the secretariat of the Convention on Biological Diversity, and funded by the European Union through the Partnership Instrument. The project began in August 2016 and is expected to be completed by August 2019.

A2.39. The objective of the project is to advance the knowledge agenda on environmental-economic accounting, in particular ecosystem accounting, by initiating pilot testing of SEEA EEA in five strategic European Union partner countries where biodiversity is a particularly significant issue, namely, Brazil, China, India, Mexico and South Africa, with a view to improving the measurement of ecosystems and their services, both in physical and in monetary terms, at the (sub)national level; mainstreaming biodiversity and ecosystems in (sub)national-level policy planning and implementation; and contributing to the development of an internationally agreed methodology and its use in partner countries.

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