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

Experimental Ecosystem Accounting

White cover publication, pre-edited text subject to official editing

Table of contents

List of tables

List of figures

Preface

To be developed.

Acknowledgements

The process of drafting these Technical Recommendations was undertaken under the auspices of the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA). The Editorial Board on the SEEA Experimental Ecosystem Accounting (SEEA EEA) Technical Recommendations provided the technical oversight of the drafting in 2016 ensuring that comments received from difference sources were taken into account during the drafting process. This role was subsequently filled by the Technical Committee on the SEEA EEA established in 2017. Many experts from countries as well as academia, international, regional and nongovernmental-organizations from different disciplines such as economics, ecosystem science, geoscience, policy and related fields participated in this exercise. We would like to acknowledge the contributions to the Technical Recommendations of individual experts and their organizations.

The Editorial Board members consisted of: Carl Obst (Editor; Institute for Development of Environmental-Economic Accounting, Australia), Lars Hein (contributing author; Wageningen University, the Netherlands), François Soulard (Statistics Canada), Rocky Harris (Department for Environment, Food & Rural Affairs, UK), Anton Steurer (Eurostat), Jan-Erik Petersen (European Environment Agency), Michael Bordt (UN ESCAP), Daniel Juhn (Conservation International), Alessandra Alfieri and Julian Chow (United Nations Statistics Division) and the World Bank. The Technical Committee consists of the same members of the Editorial Board with the exception of Daniel Juhn (Conservation International) being replaced by Gerard Bower (Statistics South Africa) and the addition of Steven May (Australian Bureau of Statistics), Sjoerd Schenau (Statistics Netherlands) and the Food and Agriculture Organization of the United Nations.

Members of the UNCEEA and other contributors from national institutions: Lisa Wardlaw-Kelly, John Power, Matt Jakab, Steve May (Australia), Sacha Baud (Austria), Norbu Ugyen, Sonam Laendup, Lobzang Dorji (Bhutan), Wadih Joao Scandar Neto, Luana Magalhaes Duarte (Brazil), Andre Loranger, Carolyn Cahill, François Soulard, Mark Henry, Gabriel Gagnon, Jennie Wang, Stéphanie Uhde, Kevin Roberts (Canada), Claudia Cortés, Jorge Gómez, Rafael Marcial Agacino Rojas (Chile), Qiong Qiu, Qin Tian, Shi Faqi (China), Gloria Lucia Vargas Briceño (Colombia), Kirsten Wismer (Denmark), Jukka Muukkonen, Petteri Vihervaara (Finland), Francoise Nirascou (France), Sven Christian Kaumanns, Beyhan Ekinci (Germany), Rakesh Kumar Maurya, Davendra Verma, James Mathew (India), Etjih Tasriah, Buyung Airlangga (Indonesia), Aldo Maria Femia, Angelica Tudini (Italy), Stephane Henriod (Kyrgyzstan), Nazaria Baharudin, Zarinah Mahari (Malaysia), Nourudeen Jaffar (Mauritius), José Arturo Blancas Espejo, Raúl Figueroa Díaz, Francisco Javier Jiménez Nava, Melanie Kolb (Mexico), Ankhzaya Byamba, Erdenesan Eldevochir (Mongolia), Bert Kroese, Sjoerd Schenau, Rixt de Jong, Stefan van der Esch, Clara Veerkamp, Arjan Ruijs, Petra van Egmond, Gerard Eding (Netherlands), David N. Barton, Per Arild Garnåsjordet, Iulie Aslaksen, Kristine Grimsrud (Norway), Vivian Ilarina, Romeo Recide (Philippines), Andrey Tatarinov (Russia), Aliielua Salani (Samoa), Johannes de Beer, Robert Parry, Amanda Driver, Ester Koch (South Africa), Nancy Steinbach and Viveka Palm (Sweden), Samuel Echoku (Uganda), Gemma Thomas, Rocky Harris, James Evans (United Kingdom), Dennis Fixler, Dixon Landers, Charles Rhodes, Dylan Rassier, Robert McKane, Roger Sayre (USA), Duong Manh Hung, Pham Tien Nam, Kim Thi Thu, Hoang Lien Son (Viet Nam).

Representatives from international organizations: Jan-Erik Petersen, Daniel Desaulty, Nihat Zal and Lisa Waselikowski, Caitriona Maguire (European Environment Agency), Anton Steurer, Ekkehard Petri and Veronika Vysna (Eurostat), Jakub Wejchert and Laure Ledoux (European Commission, DG Environment), Alessandra La Notte, Joachim Maes (European Commission, Joint Research Center), Jesús Alquézar (European Commission, DG Research and Innovation), Francesco Tubiello, Silvia Cerilli (FAO), Kimberly Dale Zieschang (International Monetary Fund), Myriam Linster, Peter van de Ven (OECD), Arnaud Comolet, Jean-Louis Weber (Convention on Biological Diversity), Barbro Elise Hexeberg, Glenn-Marie Lange, Ken Bagstad, Michael Vardon, Juan-Pueblo Castaneda, Sofia Ahlroth, Grant Cameron (World Bank), Alexander Dominik Erlewein (UNCCD), Tim Scott and Massimiliano Riva (UNDP), Emmanuel Ngok (UNECA), Michael Nagy (UNECE), Rayen Quiroga (UNECLAC), Michael Bordt (UNESCAP), Jillian Campbell, Pushpam Kumar (UNEP), Steven King, Claire Brown, Lucy Wilson (UNEP-WCMC), William Reidhead (UN-Water), Clara van der Pol (UNWTO).

Other experts that provided expert opinion: David Vačkář (Academy of Sciences of the Czech Republic), Michael Vardon, Heather Keith (Australian National University), Ferdinando Villa (Basque Centre for Climate Change), Roel Boumans (Boston University), Mahbubul Alam, Hedley Grantham, Miro Honsak, Daniel Juhn, Rosimeiry Portela, Ana Maria Rodriguez, Mahbubul Alam, Timothy Wright, Trond Larsen (Conservation International), David A. Robinson, Bridget Emmett (Centre for Ecology and Hydrology, UK), Jeanne Nel (Council for Scientific and Industrial research, South Africa), Leo Denocker, Steven Broekx, Inge Liekens, Sander Jacobs (INBO research group Nature and Society, via BEES international working group), Nathalie Olsen (International Union for conservation of Nature), Louise Gallagher (Luc Hoffmann Institute at World Wildlife Fund International), Wilbert Van Rooij (Plansup), Guy Ziv (University of Leeds), Emil Ivanov (University of Nottingham), Louise Willemen (University of Twente, Netherlands), Mariyana Lyubenova (University of Sofia, Bulgaria), Bethanna Jackson (Victoria University of Wellington), Lars Hein (Wageningen University, Netherlands).

United Nations Statistics Division staff and consultants: Alessandra Alfieri, Jessica Chan, Julian Chow, Ivo Havinga, Bram Edens (formerly with Statistics Netherlands), Mark Eigenraam, Emil Ivanov, Marko Javorsek, Leila Rohd-Thomsen, Sokol Vako. Consultants under the ANCA project: Michael Bordt, Mark Eigenraam, Lars Hein, Emil Ivanov, Carl Obst, Michael Vardon and UNEP-WCMC.

The drafting of the Technical Recommendations was supported by the United Nations Statistics Division, the United Nations Environment, the Secretariat of the Convention on Biological Diversity, the Norwegian Agency Cooperation through the Advancing Natural Capital Accounting (ANCA) project, and the World Bank WAVES partnership. The project aimed to support countries in efforts to embark on the SEEA Experimental Ecosystem Accounting with a view to improving the management of ecosystem services.

Financial contributors to the drafting of the Technical Recommendations were provided by the Norwegian Agency for Development Cooperation through the ANCA project and the European Union.

List of abbreviations and acronyms

ABS	Australian Bureau of Statistics
ARIES	ARtificial Intelligence for Ecosystem Services
BSU	basic spatial unit
C	carbon
CASA	Carnegie Ames Stanford Approach (carbon cycle model)
CBD	Convention on Biological Diversity
CICES	Common International Classification of Ecosystem Services
CPC	Central Production Classification
CSIRO	Commonwealth Science and Industrial Research Organisation (Australia)
DEM	digital elevation model
EA	ecosystem asset
EAA	ecosystem accounting area
EAU	ecosystem accounting unit
EC	European Commission
EE-IOT	environmentally-extended input-output tables
EEZ	exclusive economic zone
ENCA QSP	Ecosystem Natural Capital Accounts: Quick Start Package
ESVD	Ecosystem Services Valuation Database
ET	ecosystem type
EU	European Union
EVRI	Environmental Valuation Reference Inventory
Eurostat	Statistical Office of the European Union
FAO	Food and Agriculture Organization of the United Nations
FDES	Framework for the Development of Environment Statistics
FEGS-CS	Final Ecosystem Goods and Services Classification System
FRA	FAO Forest Resource Assessment
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GRI	Global Reporting Initiative
HRU	hydrological response units
IIRC	International Integrated Reporting Council
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change

IRWS	International Recommendations on Water Statistics
ISIC	International Standard Industrial Classification of all economic activities
ISO	International Organization for Standardization
IUCN	International Union for the Conservation of Nature
km^2	square kilometre
LCCS	Land Cover Classification System
LCEU	land cover / ecosystem functional unit
LCML	land cover meta language
LPI	Living Planet Index
LUCAS	Land Use and Cover Area Survey
LUCI	Land Utilisation and Capability Indicator
LULUCF	land use, land use change and forestry
m^2	square metre
m^3	cubic metre
mm	millimetre
MA	Millennium Ecosystem Assessment
MAES	Mapping and Assessment of Ecosystems and their Services
MEGS	Measuring Ecosystem Goods and Services
MIMES	Multiscale Integrated Model of Ecosystem Services
MMU	minimum mapping unit
N	nitrogen
NBSAP	National Biodiversity Strategic Action Plan
NCP	National Capital Protocol
NDVI	normalized difference vegetation index
NEP	net ecosystem productivity
NESCS	National Ecosystem Services Classification System
NNI	Norwegian Nature Index
NPP	net primary productivity
NPV	net present value
NSDI	national spatial data infrastructure
NSO	national statistical office
OECD	Organisation for Economic Cooperation and Development
P	phosphorous
PIM	perpetual inventory model
PSUT	physical supply and use table
SCBD	Secretariat for the Convention on Biological Diversity
SDG	Sustainable Development Goals

SEEA	System of Environmental-Economic Accounting
SEEA EEA	System of Environmental-Economic Accounting Experimental Ecosystem Accounting
SIDS	small island developing states
SNA	System of National Accounts
SUA	supply and use accounts
SWAT	Soil and Water Assessment Tool
TEEB	The Economics of Ecosystems and Biodiversity
UK	United Kingdom of Great Britain and Northern Ireland
UK NEA	UK National Ecosystem Assessment
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP WCMC	UNEP World Conservation Monitoring Centre
UN REDD+	UN Reducing Emissions from Deforestation and forest Degradation
UNSD	United Nations Statistics Division
UNU-IHDP	University of the United Nations / International Human Dimensions on Poverty Programme
US	United States
US EPA	United States Environment Protection Agency
USLE	Universal Soil Loss Equation
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
WUR	Wageningen University
WWF	World Wildlife Fund

1 Introduction

1.1 Overview of ecosystem accounting

1.1.1 Nature of the Technical Recommendations

1.1 The *Technical Recommendations in support of the SEEA 2012 - Experimental Ecosystem Accounting,* referred to as the "Technical Recommendations", provide a range of content to support testing and research on ecosystem accounting. Since the SEEA EEA's drafting in 2012, there has been much further discussion and testing of concepts and engagement with a broader range of interested experts. The core conceptual framework remains robust but some additional issues, interpretations and approaches have arisen. These issues are described in section 1.3 below. Thus, the Technical Recommendations describe advances in thinking on specific topics to ensure that the content is as up-to-date as possible in this rapidly developing field.

1.2 In addition, the Technical Recommendations summarise a wide range of data sources and methods that are relevant in compiling the various components of the ecosystem accounts. The evidence to date indicates that different approaches are possible in the compilation of ecosystem accounts and the Technical Recommendations describe the current state of play and the different pathways.

1.3 Since the field of ecosystem accounting is relatively new and is likely to continue to advance quickly given the range of testing underway, the Technical Recommendations cannot be considered a final document but rather represent a summary or stocktake of understanding at this point in time.

1.4 A formal process, endorsed by the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA) at their June 2017 meeting, has commenced with the intention to update the SEEA EEA by 2020. This process will take advantage of all relevant conceptual and practical development, and aim to put in place the first international statistical standard for ecosystem accounting. The active participation of the statistical, research and academic communities involved in ecosystem related measurement and analysis work is welcomed.

1.1.2 The conceptual motivation for ecosystem accounting

1.5 Ecosystem accounting is a coherent framework for integrating measures of ecosystems and the flows of services 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 (SEEA) Central Framework (UN, et al., 2014a). In the SEEA Central Framework, environmental assets are accounted for as individual resources such as timber resources, soil resources and water resources. In ecosystem accounting as described in the SEEA Experimental Ecosystem Accounting (SEEA EEA) (UN et al., 2014b), the accounting approach recognises that these individual resources function in combination within a broader system.

1.6 The prime motivation for ecosystem accounting is that separate analysis of ecosystems and the economy does not adequately reflect the fundamental relationship between humans and the environment. In this context, the SEEA EEA accounting framework provides a common platform for the integration of (i) information on ecosystem assets (i.e. ecosystem extent, ecosystem condition, ecosystem services and ecosystem capacity), and (ii) 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 within decision making. Consequently, there must be a strong relevance of the information set to current issues of concern. The intent of ecosystem accounting described in the SEEA EEA was for application of the framework at a national level. That is, linking information on multiple ecosystem types and multiple ecosystem services with macro level economic information such as measures of national income, production, consumption and wealth.

1.8 However, since the first release of the SEEA EEA it has proved relevant to apply the SEEA EEA ecosystem accounting framework at regional and sub-national scales. For example, for individual administrative areas such as provinces, protected areas and cities; and environmentally defined areas such as water catchments. Indeed, at these sub-national scales, the potential of ecosystem accounting can be demonstrated more easily by linking directly to the development of responses to specific policy themes or issues. Thus, a sub-national focus may be of particular interest in the development of pilot studies on ecosystem accounting and one that is facilitated by the increasing availability of data about ecosystems at this detailed level.

1.9 Importantly, using a common accounting framework for the measurement and organisation of data at sub-national levels, supports the development of a more complete national picture. This same logic also extends to the co-ordination of ecological information on trans-boundary and global scales. Overall, the co-ordination and integration of data 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 is that the biophysical environment can be partitioned to form a set of ecosystem assets. Potential ecosystem assets include forests, wetlands, agricultural areas, rivers and coral reefs. Focus to date has been on accounting for land areas, including inland waters, but there are also applications for coastal and marine areas.[1] Each ecosystem asset 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 (SNA) (EC, et al., 2009).[2] The analogous treatment implies that ecological information pertaining to ecosystems can be recorded using 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 is recorded as a combination of (i) balance sheet entries at points in time and (ii) changes in assets such as via 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 (both for ecosystem assets and produced assets) in any period are related to the productive capacity of the asset. These services also generate an income flow for the economic unit that owns or manages the asset and they are inputs to the production of other goods and services. This fundamental accounting model remains consistent throughout these recommendations. Box 1.1 provides additional introductory material on defining stocks and flows in an accounting context.

[1] For applications for marine areas (see section 3.7).

[2] As developed in economics by Solow, Jorgenson and others in the 1950s and 1960s and applied actively in national accounting from the 1990s (OECD, 2009). The SNA is the international statistical standard for the compilation of national economic accounts.

Box 1.1 Recording stocks and flows for accounting

The terms stocks and flows are commonly used in measurement discussions but can be applied in different ways from those intended from an accounting perspective. For accounting purposes, the stocks refer to the underlying assets that support production and the generation of income. Stocks are measured at the beginning and end of each accounting period (e.g. the end of the financial year) and these measurements are aggregated to form a balance sheet for that point in time. Information about stocks may be recorded in physical terms (e.g. the hectares of plantation forest) and in monetary terms.

For ecosystem accounting, the stocks of primary focus are the ecosystem assets delineated within the area in scope of the accounts. Conceptually, information about each ecosystem asset, for example information on its extent, condition and monetary value, can be recorded at the beginning and end of each accounting period and thus contribute to understanding the potential for the stock to support the generation of ecosystem services into the future (ecosystem capacity).

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

Concepts of production, consumption and income are all flow concepts. For ecosystem accounting, the relevant flows relate to the supply and use of ecosystem services between ecosystem assets and beneficiaries including businesses, governments and households. Benefits as described in ecosystem accounting are also flows.

It is important to be clear about the distinction between these two types of flows since they should not be aggregated. A common incorrect treatment is to consider improvements in the condition of ecosystem assets to be flows that can be combined with flows of ecosystem services. Instead, the appropriate treatment is to consider that improvements in condition increase the capacity of the ecosystem asset to generate ecosystem services. Thus, the different types of flows have distinct interpretations in accounting.

The distinction between stocks and the two types of flows as described here supports conveying a story about the relationship between the maintenance and degradation of ecosystem assets on the one hand, and the supply of ecosystem services on the other. By gathering information on both aspects, the accounting framework supports analysis of ecosystem capacity and sustainability in a manner aligned with standard economic and financial analysis.

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

- First, the SEEA EEA framework involves accounting for ecosystem assets in terms of both ecosystem condition and ecosystem services. Often, measurement of condition and ecosystem services is undertaken in separate fields of research, and there are relatively few studies that conceptualise ecosystem assets and services in the comprehensive manner described here.[3]
- Second, the SEEA EEA framework encompasses accounting in both biophysical terms (e.g. hectares, tonnes) and in monetary terms using various valuation techniques.
- Third, the SEEA EEA framework is designed to facilitate comparison and integration with the economic data prepared following the System of National Accounts (SNA). This leads to the adoption of certain measurement boundaries and valuation concepts that are not systematically applied in other forms of ecosystem measurement. The use of SNA derived measurement principles and

[3] One area of work is the measurement of inclusive wealth (UNU-IHDP and UNEP, 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 described here.

concepts facilitates the mainstreaming of ecosystem information with 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 large, sub-national level. However, many ecosystem measurements are conducted at a detailed, local level. The SEEA EEA framework provides an organizing structure by which detailed data can be placed in context and used to paint a rich picture of the condition of ecosystems and the services they supply.

1.1.3 The central measurement objective of ecosystem accounting

1.13 The SEEA EEA has emerged from work initiated by the international community of official statisticians, particularly the national accounts community, and their development of the SEEA Central Framework. There has long been recognition of ecosystems in the context of environmental-economic accounting, and recognition of the need to account for the degradation of ecosystems. However, the national accounting based approach described in the SEEA EEA has only emerged in recent years, as official statisticians have worked to synthesise the substantial literature concerning ecosystems and ecosystem services.

1.14 This conceptual framing is elaborated at greater length through the remaining chapters. However, at an introductory level, there is a need to articulate the broad logic or framing of a national accounting based approach to compiling ecosystem accounts. This logic is referred to here as the central measurement objective. It underpins the breadth envisaged for ecosystem accounting, the approach to the organisation of information and the potential applications. The components of the central measurement objective are the following:

1.15 *Spatial structure and ecosystem assets.* An area referred to as the ecosystem accounting area, such as a country or 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 homogenous areas of different ecosystem types such as forests, lakes, desert, agricultural areas, wetlands, etc.). While the total area being accounted for will generally remain stable, the configuration of ecosystem assets and types, in terms of their area, will change over time through natural changes and land use changes. For accounting purposes, each ecosystem asset is considered a separable asset where the delineation of assets is based on mapping mutually exclusive ecosystem asset boundaries. Ecosystem extent accounts record the compositional changes within an ecosystem accounting area, with information about different ecosystem assets usually grouped to show a summary for the different ecosystem types.

1.16 *Ecosystem condition.* Each ecosystem asset will also change 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. These changes may be due to natural causes or human/economic intervention. Recording the changes in condition of multiple ecosystem assets within a country (or sub-national region) is a fundamental ambition of ecosystem accounting.

1.17 The measurement of ecosystems often overlaps with the measurement of biodiversity. In the ecosystem accounting framework, biodiversity is considered to be a key component in the measurement of ecosystem assets rather than being considered an ecosystem service in its own right. This treatment aligns with accounting practice that distinguishes clearly between the assets that underpin production which can improve or degrade over time, and the production and income that is generated from the asset base.

1.18 *Supply of ecosystem services.* Either separately, or in combination, ecosystem assets supply ecosystem services. Most focus at this time is on the supply of ecosystem services (including provisioning, regulating and cultural services) to economic units, including businesses and households. These are considered final ecosystem services. The ecosystem accounting framework also supports recording flows of intermediate ecosystem services which are flows of services between ecosystem assets. Recording these 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 be able to estimate a contribution from each ecosystem asset to the total supply.

1.20 *Basket of ecosystem services.* Generally, each ecosystem asset will supply a basket of different ecosystem services. The conceptual 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 aspect of accounting. In the SEEA EEA, the measurement boundary for final ecosystem services is defined to support data integration 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/traditional goods and services is a key feature of the SEEA EEA approach. Depending on the ecosystem service, the user (e.g. household, business, government) may receive the ecosystem service while either located in the supplying ecosystem asset (e.g. when catching fish from a lake) or located elsewhere (e.g. when receiving air filtration services from a neighbouring forest).

1.22 *Linking to benefits.* Flows of ecosystem services are distinguished from flows of benefits. In the SEEA EEA, the term benefits is used to encompass both the products (goods and services) produced by economic units as recorded in the standard national accounts (SNA benefits) and 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 well-being or welfare that is influenced by the consumption or use of benefits. 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 directly such measurement.

1.23 *Valuation concepts.* Given the ambition of integration with standard economic accounting data, the derivation of estimates in monetary terms 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, or the estimation of extended measures of national wealth. The core valuation concept applied in the SNA and used also for ecosystem accounting is exchange value, i.e. 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 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 (including, for example, the appreciation of nature when viewing ecosystems) between economic units and ecosystem assets. 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. A range of techniques have been developed for the valuation of non-market transactions and these can be applied to provide estimates of the value of the supply and use of ecosystem services in monetary terms, noting that there exists a range of challenges in implementation and interpretation of these values.[4]

1.25 Based on the estimates of ecosystem services in monetary terms, the value of the underlying ecosystem assets can be estimated using net present value techniques. That is, 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 for ecosystem assets would be used, for example, for agricultural land. However, it is likely that the observed market values will not incorporate the full basket of ecosystem services supplied, and, on the other hand, will also reflect values that are influenced by factors other than the supply of ecosystem services, e.g. 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 and there is no explicit incorporation of non-monetary valuation approaches. Consequently, the core monetary ecosystem accounts will not provide all of the information needed to support all decision making contexts. Nonetheless, the broad information set of the ecosystem accounts, in particular accounts in physical terms, will, at a minimum, provide coherent context for all decision making situations.

1.27 Ultimately, meeting this central measurement objective will require a substantive collaboration of skills and data. The remainder of these Technical Recommendations provide guidance on directions and approaches that can be applied and are under active testing and implementation at national and sub-national levels.

1.1.4 Measurement pathways

1.28 The national accounts framing for ecosystem measurement underpins the discussion in the remainder of these Technical Recommendations. It is clear however that there are other motivations and rationales for the measurement of ecosystems and different choices of concepts and measurement boundaries may be used, particularly concerning the valuation of ecosystem services and ecosystem assets. Notwithstanding these differences in motivation and rationale, experience to date suggests that much of the information required for all ecosystem measurement is either common or complementary. There is thus much to be gained from ongoing discussion and joint research and testing.

1.29 Even within the national accounting framing of ecosystem measurement outlined above, there are a number of alternative measurement pathways, i.e. ways in which the relevant data and accounts might be compiled. The SEEA EEA, like the SEEA Central Framework and the SNA, does not focus on *how* measurement should be undertaken or the appropriate sources and methods. Rather, it describes *what* variables should be measured and the relationships among different variables. Since these Technical Recommendations are intended to support compilation, the focus here

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

is on establishing approaches to measurement. At the same time, the Technical Recommendations do not provide a “cookbook” describing the precise “quantities of ingredients” required to compile a set of ecosystem accounts. As the testing and development of ecosystem accounting continues, it is expected that more concrete advice will be able to be documented.

1.30 The different pathways to ecosystem accounting measurement are best thought of as being located along a spectrum. At one end are approaches which involve detailed spatial modelling and articulation of ecosystem assets and ecosystem service flows. These approaches might be considered as “fully spatial”. At the other end of the spectrum are approaches that are less explicit in their spatial definition and seek to provide a broad overview of trends in key ecosystem types and services – a “minimum spatial” approach. In practice, ecosystem accounting is being undertaken between these two extremes with the degree of spatial detail being utilised depending on the availability of data and resources for compilation, on the type of research question and may change over time. The following paragraphs give a general sense of the nature of these different approaches.

1.31 *Minimum spatial approach.* Minimum spatial measurement commences from a more traditional, aggregate, national accounting perspective. It will generally be undertaken at a national (or large, sub-national region) level and aims to provide broad context to support discussions and decisions pertaining to the use of environmental assets and ecosystems. To this end, the starting point will commonly be identifying (i) a specific basket of ecosystem services that are considered most likely to be supplied by ecosystems and (ii) a limited number (perhaps around 10) of ecosystem types (e.g. forests, agricultural land, coastal areas). Flows of each ecosystem service, attributed to ecosystem type where relevant, are then measured and, if relevant for decision making, relevant values can be estimated in order to derive measures of the monetary value of ecosystem services and assets.

1.32 The key feature of a minimum spatial approach is that there is no requirement for a strict or complete spatial delineation of individual ecosystem assets and 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 but, equally, will not be able to provide information to analyse the detailed implications of policy options since the characterizations of ecosystem assets are generally coarse (i.e. using a limited number of ecosystem types) and need not be spatially specific. Thus, the relative size (area) of an ecosystem type will often heavily influence an ecosystem assessment, as distinct from an ecosystem assets’ relative importance in overall ecosystem functioning. Consequently, for example, recognizing the role of wetlands or linear features of the landscape, which are commonly relatively small in terms of area, may be more difficult. Nonetheless, using a minimum spatial approach does provide an entry point for recognition of the potential for ecosystem accounting and provides an information base upon which more detail can be added over time.

1.34 *Fully spatial approaches.* Fully spatial approaches will generally commence from a more ecological perspective where there is a desire to reflect, as a starting point, distinctions between ecosystem assets at a fine spatial level. Using ecosystem type classifications, the aim is to delineate 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 they supply is a particularly relevant exercise in fully spatial approaches. The measurement of ecosystem services will generally be 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, fully spatial approaches will be more resource intensive and implementation will require more ecological and geo-spatial expertise since much higher levels of ecosystem specific information would be expected to be used. The approach increases the potential for ecosystem accounting to provide information that is highly relevant in assessing site specific trade-offs and heightens the potential for the ecosystem accounting framework to assist in organizing a large amount of existing ecological data. However, it raises challenges of data quality and aggregation that must be overcome if broader accounting stories are to be presented.

1.36 As noted above, from a measurement perspective, the key difference between the minimum and fully spatial approaches is the extent to which the information underlying the accounts is integrated on the basis of a co-ordinated spatial data system. Conceptually, the ecosystem accounting framework is spatially based and hence, ideally, measurement should aim towards adopting approaches that are more spatial in nature. With this in mind, the recommendations here tend towards descriptions that are spatially oriented, including support for the development of national spatial data infrastructure (NSDI) and associated investments in additional spatial datasets.

1.37 However, it is reiterated that whether the entry point for measurement is minimum spatial or more fully spatial, there is conceptual alignment and the different approaches only reflect different ways of tackling the measurement challenge.[5] At the same time, it would not be expected that each approach would provide the same estimates for a given region or country. In this context, by providing a standard set of definitions and measurement boundaries, the ecosystem accounting framework gives a platform for comparing the results from different measurement approaches and, over time, building a rich, comprehensive and coherent picture of ecosystems. Thus, notwithstanding the potential for flexibility in measurement approaches, provided the same accounting definitions are applied, and using consistent classifications, then comparison between measurement in different locations and over time can be undertaken.

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 relating to environment and natural resources management, recognising that the management of these resources is of relevance also in economic, planning, development and social policy contexts.

1.39 <u>Detailed, spatial information on ecosystem services supply.</u> Ecosystem service supply accounts provide information on the quantity and location of the supply of ecosystem services. This gives insight in the wide range of services that are offered primarily, but not only, by natural and semi-natural vegetation. This information is vital to monitor the progress towards policy goals such as achieving a sustainable use of ecosystem assets and preventing further loss of biodiversity. Defining and quantifying ecosystem services and the factors that support or undermine them is needed to highlight the importance of all types of ecosystems. Protection of the natural

[5] The analogy in standard national accounts compilation is between the estimation of GDP using supply and use tables with associated product and industry details and the estimation of GDP through measurement of factor incomes and final expenditures. Conceptually, these two GDP measurement approaches are aligned but they will provide different estimates in practice and will support different policy and analytical uses.

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. The information should also be highly relevant for land use planning and the planning of, for instance, infrastructure projects. For example, the potential impacts of different locations for a new road on the overall supply of ecosystem services can be easily observed.

1.40 Monitoring of the status of ecosystem assets. The set of ecosystem accounts provide detailed information on changes in ecosystem assets. The condition account reveals the status using a set of physical indicators, and the monetary accounts provide an aggregated indicator of ecosystem asset values. Although this indicator does not indicate the 'total economic value' of ecosystems, it does provide an indication of the value of the contribution of ecosystems to consumption and production, as measured with exchange values – for the ecosystem services included in the accounts. The overall value may be of less relevance for supporting decision making, but *changes* in this value would be a relevant indicator for assessing overall developments.

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

1.42 Monitoring the status of biodiversity and indicating specific areas or aspects of biodiversity under particular threat. Compared to existing biodiversity monitoring systems, the accounting approach offers the scope – when biodiversity accounts are included – to provide information on biodiversity in a structured, coherent and regularly updated manner. Aggregated indicators for administrative units including for countries and continental scale (e.g. Europe) provide information on trends in biodiversity as well as species or habitats of particular concern. In this context, the biodiversity account can include information on species important for ecosystem functioning (e.g. 'key-stone' species indicative of environmental quality), and species important for biodiversity conservation (e.g. the presence and/or abundance of rare, threatened and/or endemic species). Where biodiversity accounts are presented as maps of biodiversity indicators, specific areas of concern or 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. To support ongoing reporting requirements as well as providing information to support discussion of emerging issues, the accounts provide information that is:

- comprehensive - covering ecosystem services and assets, maps and tables, physical and monetary indicators, covering a wide range of ecosystem types and services
- structured - following the international framework of the SEEA aligned with the SNA
- coherent - integrating a broad range of datasets to provide information on ecosystem services and assets
- spatially referenced – linking data to the scale of ecosystems and allowing the integration of data across difference accounts.

1.44 Ideally, accounts should be updated on a regular basis, e.g. bi-annual or annual, taking into account source data availability and user needs. This means 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, say, an assessment of new investment in infrastructure, can typically take anytime from half a year to several years. In large part this reflects 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 this information need. Assessment of specific policies or investments will likely require additional information beyond that presented in the ecosystem accounts, but, 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. This allows more focus on the outputs from reviews, rather than evaluating the data inputs. This is analogous to the way in which a common, core set of economic data underpins economic modelling.

1.45 Monitoring the effectiveness of various policies. The accounts are an important tool to monitor the effectiveness of various regional and environmental policies, by allowing the tracking of changes in the status of ecosystems and the services they provide over time in a spatially explicit manner. The spatial detail of the accounts allows comparison of developments in areas influenced by policies with areas with less or no influence of specific policy decisions. In particular, the notion of return on investment may be applied by assessing the extent to which expenditure on a specific program or a particular piece of regulation has made 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 this context, the measurement of the value of ecosystem services in exchange values supports direct integration with standard financial and national economic accounting data. Consequently, the data can be used 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 consider ecosystems through multiple analytical lenses appears a strong motivation to continue development of valuations for accounting purposes.

1.2 Scope of the Technical Recommendations

1.2.1 Connection to the SEEA Central Framework

1.47 The 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 accounting for the way in which individual assets and resources function together. Consequently, there are often strong connections between the accounting for individual environmental assets described in the SEEA Central Framework and measures of ecosystem assets and ecosystem services. Perhaps the key difference in measurement scope is that in the SEEA EEA the number of ecosystem services that are included is much larger than in the SEEA Central Framework. Thus, while the SEEA Central Framework incorporates measurement related to provisioning services (such as flows of timber, fish and water resources), the SEEA EEA extends this scope and also includes regulating and cultural services.

1.48 There are therefore important advantages for ecosystem accounting in using the range of materials that have been developed relating to the measurement of water resources (including SEEA Water (UN, 2012b)), agriculture, forests and timber, fisheries, (SEEA Agriculture, Forestry and Fisheries (FAO, 2016)) and land. While these materials have not generally been developed for ecosystem accounting purposes, they will support the development of relevant estimates and accounts, especially in relation to methods and data sources. Also, these documents describe potential applications of accounting that can provide a useful focus for compilers.

1.49 The SEEA EEA identified two areas of accounting, accounting for carbon and accounting for biodiversity, that reflect adaptations of the individual environmental asset accounting described in the SEEA Central Framework. The emerging range of materials in these 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 9 under the heading of thematic accounts. Importantly, the compilation of accounts for these specific asset types will be of direct application in specific policy and analytical situations, as well as being of direct use in compiling ecosystem accounts.

1.2.2 Connection to other ecosystem accounting and similar materials

1.51 The Technical Recommendations incorporate findings reflected in a range of other technical materials on ecosystem accounting developed through 2013 to 2015[6] and also aim to reflect as effectively as possible, the learning and experience from the increasing number of projects and initiatives on ecosystem accounting. These materials and projects have been developed by different agencies and in different contexts but have helped in the testing of SEEA EEA by providing technical options and communicating the potential of a national accounting approach to ecosystem measurement. A short, non-exhaustive, summary of various projects and initiatives is provided in Annex 1. Also noted here are research papers and journal articles on ecosystem accounting that continue to be released. These are referenced through the chapters of the Technical Recommendations.

1.2.3 The audience for the Technical Recommendations

1.52 The primary audiences for the Technical Recommendations are (i) people working on the compilation and testing of ecosystem accounting and related areas of environmental-economic accounting; and (ii) people providing data to those exercises, perhaps as part of separately established ecosystem and biodiversity monitoring and assessment programs. Ecosystem accounting is a multi-disciplinary exercise, and requires the integration of data from multiple sources. Thus, testing will require the development of arrangements involving a range of agencies including, at a minimum, national statistical offices, environmental agencies and scientific institutes.

1.53 The Technical Recommendations are intended to be accessible to people of various disciplinary backgrounds but it is accepted that different people will have

[6] Examples include Ecosystem Natural Capital Accounts: A Quick Start Package (ENCA QSP) (Weber, 2014a); Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States (UNEP, 2015); Designing Pilots for Ecosystem Accounting (World Bank, 2014); and Mapping and Assessment of Ecosystems and their Services (MAES) (2nd report) (Maes, et al., 2013).

different levels of understanding about different parts of the ecosystem accounting model. It is likely that those with a background or understanding of national or corporate accounting will find the concepts and approaches described more accessible. For those without this background, Annex 2 has been included to provide some insight into key features of the national accounting based approach to measurement that underpins the ecosystem accounting model.

1.54 The Technical Recommendations should also assist those who will use the information that emerges from sets of ecosystem accounts by providing an explanation of 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 document. As a starting point for considering potential applications, readers are directed to the Policy Forum document from November 2016 (World Bank, 2017).

1.2.4 Implementation of ecosystem accounting

1.55 By its nature, ecosystem accounting is an inter-disciplinary undertaking with each discipline, including statistics, economics, national accounts, ecology, hydrology, biodiversity and geography (among many others), bringing its own perspective and language. In order to obtain the benefits from an integrated approach, institutional co-ordination and cooperation is required to support the compilation and use of accounting based solutions. The compilation of ecosystem accounts will require establishing teams with an appropriate mix of skills but also building networks with established experts in different institutions to ensure that the best information and techniques relevant to the particular country or region can be accessed. In addition, the broader development and implementation of ecosystem accounting will require establishing networks and arrangements involving policy and decision makers, local communities and other stakeholders. As a result of the requirement for the involvement of many skills and stakeholders, there are ample opportunities for those involved in all areas of measurement and policy to become involved 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 in terms of information requirements between different projects, notwithstanding differences in purpose and analytical intent. Indeed, it is likely to be the case that advancements in ecosystem accounting can support the organisation of information required for other projects analysing the connections between the environment and economic and human activity.

1.57 Given the need for involving many areas of expertise, an important aspect of implementation is the allocation of resources to co-ordination, data sharing and communication. Thus, the implementation task is not solely a technical measurement challenge. Appropriate institutional arrangements and resourcing to support ongoing engagement and communication are also required.

1.58 One particular motivation for the participation of non-accounting and non-statistical experts in ecosystem accounting projects is that the implementation of ecosystem accounting is intended to establish ongoing measurement programs. This is different from undertaking, as is common in environmental assessments, one-off or short term studies of specific areas or environmental themes. The long-term ambitions, paralleling the ongoing measurement of GDP and economic statistics, suggests that engagement with relevant experts must also become ongoing allowing the opportunity to build and improve measurement over time and contribute to the compilation of an enduring dataset. In turn, these datasets should underpin further research and analysis, ideally leading to a strong virtuous circle of information.

1.59 The development of the SEEA has been led by the official statistics community. Thus, while many different agencies and disciplines will need to be involved in implementation, there are a number of aspects of ecosystem accounting that warrant the involvement of national statistical offices (NSO) these are listed in Box 1.2.

1.60 The actual role an NSO might play will depend on the scope of the activities it has traditionally been involved in. For example, some NSO have strong traditions in relation to working with geographic and spatial data, and others have a history of development and research. NSO with these types of experience may be able to play leading roles in the development of ecosystem accounting. Those NSO without this type of experience may still play an important role.

1.61 Non-NSO agencies will play an important role in ecosystem accounting. Of particular note are those agencies that lead work on geographic and spatial data 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 from the emerging work on ecosystem accounting is that collaborative approaches are essential to progress measurement in this area.

1.62 General advice on establishing programs of work for the implementation of SEEA is provided in the SEEA Implementation Guide (UNSD, 2013) and various tools 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 the experiences in other countries and regions. The UNSD, World Bank WAVES SEEA and FAO SEEA (SEEA for Agriculture, Forestry and Fisheries) related websites provide links to relevant reports.

Box 1.2: Potential roles of National Statistical Offices in ecosystem accounting

The following roles are commonly played by all statistical offices. All of these roles suggest that there is a place for NSO in the development of ecosystem accounting under a variety of possible institutional arrangements. Those agencies leading ecosystem accounting testing and research are encouraged to utilise the expertise of NSO in these areas.

- As organisations that work with large and various datasets, NSO are well placed to contribute their expertise in the collection and organisation of data from a range of different sources.
- A core part of the role of NSO is the establishment and maintenance of relevant definitions, concepts and classifications. The area of ecosystem accounting has many examples of similar concepts being defined differently and there are known to be multiple classifications of ecosystem services and ecosystem types. The involvement by NSO in this area of work would be beneficial.
- NSO have capabilities to integrate data from various sources to build coherent pictures of relevant concepts. Most commonly NSO focus on providing coherent pictures in relation to socio-economic information and this capability can be extended to also consider environmental information.
- NSO work within broad national and international frameworks of data quality that enable the assessment and accreditation of various information sources and the associated methodologies in a consistent and complete manner.
- NSO have a national coverage and creating national economic and social pictures is a relatively unique role undertaken by NSO. 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 geo-spatial statistics.
- NSO can present an authoritative voice by virtue of the application of standard measurement approaches, data quality frameworks and their relatively unique role within government.

1.3 Conceptual developments in SEEA EEA incorporated into the Technical Recommendations

1.3.1 Introduction

1.63 The Technical Recommendations build directly on the conceptual framework for ecosystem accounting described in the SEEA EEA. For the most part, they provide additional explanation and direction for compilation. However, there are some areas in which clarifications and reinterpretations of the conceptual model have been required. This reflects the ongoing discussion and consideration of ecosystem accounting since the completion of the SEEA EEA in 2013. There are five main areas in which conceptual developments are introduced.

1.3.2 The treatment of spatial units

1.64 The treatment of spatial units for ecosystem accounting has been advanced and clarified in a number of ways in the Technical Recommendations (see Chapter 3 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 (EAA), formerly ecosystem accounting unit (EAU). Within the EAA, individual ecosystem assets (EA), formerly land cover/ecosystem functional units (LCEU), are delineated. These areas are now clearly the underpinning conceptual area for ecosystem accounting delineating 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 that the delineation of EA will, ideally, involve the use of a range of ecological and non-ecological criteria, including vegetation type, soil type, hydrology, and land management and use. These criteria can be used to classify EAs to various ecosystem types (ET). Generally, ecosystem accounts will be compiled and presented for areas of different ET rather than for individual EA.

1.66 Finally, the Technical Recommendations, retain the use of basic spatial units (BSU). However, it has now been clarified that BSU may be formed in various ways including via the use of a reference grid, or through the delineation of polygons. The flexible approach to defining BSU reflects that in ecosystem accounting work, the BSU is part of the measurement approach rather than an underpinning conceptual unit.

1.3.3 Account labelling and structure

1.67 The SEEA EEA included a range of accounts but, on reflection, the structure and naming conventions needed further development. As described in Chapter 2, there are three key advances:

- A distinction has been drawn between ecosystem accounts and thematic accounts. Ecosystem accounts are those covering specifically 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 are those for specific topics including land, carbon, water and biodiversity. Data from thematic accounts may be used in compiling ecosystem accounts and may also provide important contextual information in their own right and support analysis of ecosystem accounting information.

- Some of the ecosystem accounts have been relabelled – for example the ecosystem monetary asset account which was formerly the ecosystem asset account (in monetary terms).
- In terms of account structure most are similar to that described in SEEA EEA. The exception is the supply and use account for ecosystem services which now has a more articulated structure building on the physical supply and use tables of the SEEA Central Framework.

1.3.4 The measurement of ecosystem services

1.68 In the SEEA EEA, the focus for ecosystem accounting was clearly on measuring the contribution of final ecosystem services to the production of benefits. However, there are two aspects surrounding this focus that have been clarified in these Technical Recommendations.

1.69 First, there is a clearer explanation that the incorporation of final ecosystem services in the accounting framework reflects an extension in the production boundary compared to the production boundary defined in the SNA (and which underpins the measurement of GDP). Thus, in a national accounting context, the integration of final ecosystem services leads to an expansion in measures of output.

1.70 This 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 two cases arise. Where the 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 recording an input to the production of the SNA benefits. However, where the ecosystem services contribute to goods and services outside the SNA production boundary (non-SNA benefits) there will be a direct increase in the level of GDP. Overall, it would be expected that the extension of the production boundary will broaden of measures of production, consumption and income and hence the associated value of assets that supply the services. A stylised numerical example showing these results is presented in table 8.1.

1.71 Second, in the Technical Recommendations there is a clearer recognition of the potential to record 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 focus only on final services serves to recognise the important role that these processes play in directly supporting economic and human activity. Recognising that intermediate services can also be recorded in the accounting framework supports a better conceptualisation of the connections and dependencies between ecosystem assets. This illustrates the potential of ecosystem accounting to recognise the contributions of all ecosystems and associated ecosystem processes wherever they are located and to understand the potential impacts of economic production and consumption on ecosystem assets.

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

1.3.5 Ecosystem condition

1.73 The concept of ecosystem condition remains the same as in the SEEA EEA. However, on reflection, there was a need to enhance the measurement of condition and hence some important framing of this issue has been included in the Technical Recommendations. This framing introduces the notion of top-down and bottom-up approaches to measurement, recognises that some indicators of condition may relate to fixed characteristics as distinct from variable ones, and there is important clarification on the issue of measuring condition from small to larger scales. On this last point, a continuum is described from the definition of indicators for individual characteristics for a single ecosystem type, up to the potential to define comparable indicators across ecosystem types with multiple characteristics.

1.74 A more general point is that it is also recognised more explicitly that the measurement of condition will depend on the current pattern of land use/management and the associated mix of ecosystem services. In turn, this is likely to affect the way in which ecosystem units are delineated.

1.3.6 Ecosystem capacity

1.75 In the SEEA EEA, ecosystem capacity was mentioned but not defined. Through the development of the SEEA EEA, the relevance of the concept was recognised but no agreement could be found on how it might be best described in an accounting context. Since the release of the SEEA EEA, it has become increasingly clear that the concept of ecosystem capacity that links the concepts of ecosystem condition and ecosystem services is in fact quite fundamental in 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 These Technical Recommendations therefore provide a more thorough description of the concept of ecosystem capacity from both a biophysical and monetary perspective propose a definition and outline some associated measurement matters. The majority of the discussion takes place in Chapter 7 reflecting that the discussion of ecosystem capacity requires the integration of measures of ecosystem extent, condition and services. As yet, no final position has been reached regarding the definition and measurement of this concept and research is continuing on this topic.

1.4 Structure of Technical Recommendations

1.77 All aspects of ecosystem accounting as described in SEEA EEA are within scope of the Technical Recommendations. Discussion of them is structured in the following way.

- Chapter 2 introduces the ecosystem accounting framework, the ecosystem accounts and describes approaches to measurement.
- Chapter 3 summarises the spatial areas used in ecosystem accounting and the compilation of ecosystem extent accounts.
- Chapter 4 describes the measurement of ecosystem condition.

- Chapter 5 introduces accounting for flows of ecosystem services with a description of the ecosystem supply and use account, discussion of some of the key boundary and classification related issues and possible approaches to measurement.
- Chapter 6 summarises the valuation of ecosystem services in monetary terms.
- Chapter 7 considers the issue of accounting for ecosystem assets in monetary terms and the relationship to measures of ecosystem capacity and degradation.
- Chapter 8 updates the discussion in the SEEA EEA Chapter 6 on the integration of ecosystem and economic information via the accounting framework.
- Chapter 9 provides an introduction to accounting for various thematic accounts related to ecosystems namely land, carbon, water and biodiversity.

2 Ecosystem accounts and approaches to measurement

Key points in this chapter

The core ecosystem accounting framework from the SEEA EEA provides a robust framework for 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 used in the compilation of accounts from fully spatial to minimum spatial approaches. The choice of approach will reflect differences in data availability and the type of analytical or policy question of primary interest.

There are five broad compilation 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 and then on 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 (i) the selection of indicators to measure ecosystem condition and (ii) 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 by progressively developing individual accounts and then working towards ensuring a coherence and consistency between them.

An ecosystem accounting approach will be most useful when accounts are compiled on an ongoing basis such that a time series of coherent information can be analysed and relationships and trends established.

2.1 Introduction

2.1 This chapter provides an overview of ecosystem accounting; relevant details are provided in the following chapters. The chapter complements and builds on the text in SEEA EEA Chapter 2 by providing additional descriptions of key elements of the ecosystem accounting framework. In doing so, the section also provides some additional material to reflect the ongoing developments in ecosystem accounting.

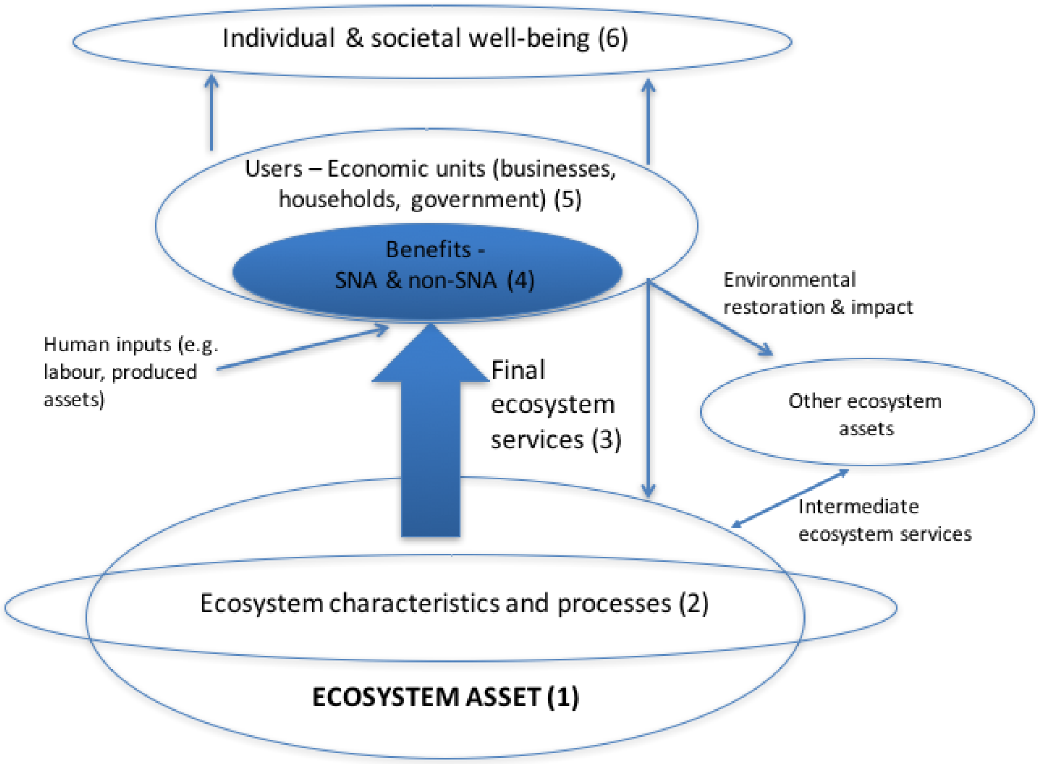
2.2 The SEEA EEA ecosystem accounting framework

2.2 The SEEA EEA ecosystem accounting framework has five main components that are reflected in Figure 2.1. Starting at the bottom of Figure 2.1, the framework is based around accounting for the various biotic and abiotic components within an **ecosystem asset (1)** that is represented by a spatial area.[7] The delineation of the area that defines an ecosystem asset is required for accounting purposes and should be considered a statistical representation of ecosystems, even though by their nature they are not discrete systems that align to strict spatial boundaries. There will be different types of ecosystem assets within a territory (e.g. forests, wetlands) which will need to

[7] Some of these components may be accounted for individually using the asset accounting descriptions in the SEEA Central Framework – e.g. accounts for timber, water and soil.

be distinguished. Approaches to the delineation of spatial areas for ecosystem accounting are described in Chapter 3.

Figure 2.1: Ecosystem accounting framework



Source: Adapted from SEEA EEA Figure 2.2, UN et al., 2014b.

2.3 Each ecosystem asset has a range of relevant **ecosystem characteristics and processes (2)** that together describe the functioning of the ecosystem. While each ecosystem asset is uniquely defined, ecosystem processes will generally operate both within and across individual ecosystem assets. Thus, while in Figure 2.1 ecosystem assets are shown 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 is measured by assessing the ecosystem asset's **extent and condition** using indicators of the relevant ecosystem asset's area and characteristics. The extent and condition of an ecosystem asset will be affected by natural changes and also by human activity in the landscape. While each ecosystem asset is considered separable for accounting purposes there will be 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 3 and the measurement of ecosystem condition is described in Chapter 4.

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 (businesses, governments and households) and may be grouped into provisioning services (i.e. those relating to the supply of food, fibre, fuel and water); regulating services (i.e. those relating to actions of filtration, purification, regulation and maintenance of air, water, soil, habitat and climate) and cultural services (i.e. those relating 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, 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 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)** being 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 5 and the valuation of ecosystem services is described in Chapter 6. Ecosystem accounting does not focus on the measurement of individual or societal well-being. It is noted however, that in some decision-making contexts there may be direct interest in the assessment of well-being and the choice of valuation approach may be varied to take this in account. 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 ecosystem accounting is to understand the potential for ecosystem assets to provide services into the future and hence contribute to sustainable overall individual and social well-being. In this context, the scientific literature on ecosystem accounting has proposed four concepts in relation to ecosystem services (Hein et al., 2016, building upon among others Bagstad et al., 2014 and Schröter et al., 2014). These are: (i) the *actual flow* of ecosystem services, as recorded in the ecosystem services supply and use account; (ii) the *capacity* of ecosystems to supply services, corresponding to the sustainable flow of services subject to there being demand for such services (flow equals capacity for regulating services); (iii) the *potential supply* of services, indicating the potential, sustainable flow of services assuming no limitations in demand for the service (hence potential flow is a function of ecosystem characteristics only, it is not influenced by the presence of people using the service); and (iv) *ecosystem capability*, reflecting the ability of the ecosystem to generate services if it where managed in a different way. Potential supply and capability are concepts that are relevant for environmental management, and less so for accounting (although it can be noted that condition accounts are most directly linked to the potential of the ecosystem to supply services rather than to the actual service supply that also depends upon human use of the ecosystem). These concepts are further discussed in Chapter 7.

2.10 Finally, the aggregate contribution and role of all ecosystem assets will be 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 8.

2.3 The ecosystem accounts

2.3.1 Placing the ecosystem accounts in context

2.11 There are five core ecosystem accounts as listed in 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, different accounts will be of greater or lesser focus in compilation. The options for measurement and the links to the different accounts are described later in this chapter.

Table 2.1: The 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 These five accounts reflect a system of accounts that present a coherent and comprehensive view of ecosystems.[8] At the same time, each account has merit in its own right and does not rely on other accounts to provide 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 encompassing the measurement of national income and institutional sector and national wealth. Indeed, accounts which integrate the ecosystem and the economic accounts can be compiled as described in Chapter 8.

2.13 By providing the basis for the integration of ecosystem data with the economic accounts of the SNA, the SEEA EEA ecosystem accounting framework incorporates a range of choices in measurement, particularly in terms of the scope of ecosystem services and the concepts used for valuation. It would be possible to design complementary ecosystem accounts to those described here, for example by adopting different valuation concepts, to suit particular policy and analytical purposes while still applying the same basic accounting framework portrayed in Figure 2.1. Such complementary accounts are not discussed here but may be an area for further discussion and research.

2.14 As recognised in the previous section, ecosystem assets comprise biotic and abiotic components and a range of these components are the subject of direct environmental-economic accounting, for example accounts for timber resources, water resources, land and soil resources. Accounts for individual components can provide information that contributes directly to the measurement of ecosystem assets and ecosystem services but also provide useful information in a stand-alone context. In the context of ecosystem accounting these various accounts are termed thematic accounts. Accounts for four themes are discussed in Chapter 9, namely accounts for land, water, carbon and biodiversity. Chapter 9 also notes other themes for which accounts may be compiled.

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

[8] Note that there is not one, single, all-encompassing ecosystem account.

2.16 However, it is recognised that the ecosystem accounting framework may also be applied with a more tailored focus. For example, the framework may also be applied for measurement of:

- A single ecosystem asset or ecosystem type (e.g. a forest/s) and/or a single ecosystem service (e.g. water regulation). For individual provisioning services, there may be a direct connection to natural resource accounting described in the SEEA Central Framework Chapter 5.
- 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 this type may be of interest to understand the 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 management arrangements in place (e.g. national parks and protected areas).

2.17 In all of these "reduced" or tailored cases, the logic of the ecosystem accounting framework described above can be applied. Indeed, 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 lies heavily in the various projects adopting consistent measurement boundaries and classifications but therein lies a prime motivation for application of a common ecosystem accounting framework.

2.18 Another tailored application of ecosystem accounting is to focus on accounts for regions within a country. This may include accounts at sub-national administrative levels or for well-defined ecological areas (e.g. water catchments). Further, accounts at a multi-country level (e.g. all European Union countries) can be envisaged. Again, 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 most effective. Typically, an initial set of accounts including an ecosystem extent account, condition account and ecosystem services supply and use account for a single year would be compiled. An initial development phase may take between one and two years. Depending on the initial scope, extension to develop accounts 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 incorporate successive improvements in the accounts and underlying sources and methods. The rate of progress will depend on a range of factors including the available resources, complexity of account design (e.g. number of ecosystem types and ecosystem services), data availability, the degree of experience with spatial analysis of ecosystems and ecosystem services and the extent of collaboration between relevant agencies that can be achieved.

2.3.2 Ecosystem extent accounts

2.20 The common starting point for all ecosystem accounting work will be organizing information on the extent or area of different ecosystem types within a country. This is important for four reasons. First, the task of defining the ecosystems of interest for accounting purposes is by no means straightforward and a balance between scale of analysis, available data and policy questions will need to be found. It is very appropriate to start this discussion by examining the definition of ecosystem assets and the delineation of their extent.

2.21 Second, the organisation of information required to establish an ecosystem extent account 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 shown below, gives a clear indication of the nature of accounting for assets in a SEEA context. The requirement to produce a time series of data to allow meaningful comparison between the opening and closing of an accounting period is clear.

2.23 Fourth, while the ecosystem extent account provides a clear base for the development of the other ecosystem accounts, it also provides important information in its own right. For example, when compiled at appropriate levels of detail, ecosystem extent accounts provide a common basis for discussion among stakeholders of the composition of ecosystem types within a country and provide an assessment of ecosystem diversity at a national level. Extent accounts can also support the derivation of indicators of deforestation, desertification, urbanisation and other forms of land use driven change.

2.24 The structure of the basic ecosystem extent account and relevant data sources are described in Chapter 3.

2.3.3 Ecosystem condition accounts

2.25 A central feature of ecosystem accounting is organizing biophysical information on the condition of different ecosystem assets across the area for which the ecosystem accounts are produced (the 'Ecosystem Accounting Area' or EAA). The condition account provides insight in how ecosystems within the EAA change, and how those changes may influence the flows of ecosystem services supplied by those ecosystems. The ecosystem condition account is compiled in physical terms using a variety of indicators for selected characteristics. The structure of the ecosystem condition account is described in Chapter 4.

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

2.3.4 Ecosystem services supply and use accounts

2.27 The supply of ecosystem services by ecosystem assets and the use of these services by economic units, including households, is one of the central features of ecosystem accounting. These are the flows that reflect the link between ecosystem assets and economic and human activity. The supply and use account records the actual flows of ecosystem services supplied by ecosystem assets and used by economic units during an accounting period and may be compiled in both physical and monetary terms. An extensive discussion of the ecosystem services supply and use account is in Chapter 5.

2.3.5 *Ecosystem monetary asset account*

2.28 Asset accounts are designed to record information on stocks and changes in stocks (additions and reductions) of ecosystem assets. This includes accounting for ecosystem degradation. The ecosystem monetary asset account records this information in monetary terms, based on valuation of ecosystem services and connecting to information ecosystem extent and condition. The ecosystem monetary asset is described in Chapter 7.

2.3.6 *Related accounts and concepts*

2.29 The set of ecosystem accounts just summarised above reflects a complete accounting coverage for all ecosystem assets and ecosystem services within a given ecosystem accounting area in both physical and monetary terms. However, these accounts and the information they contain cannot be considered in isolation. Two connections to other accounts must be described.

2.30 The first connection concerns the integration of ecosystem accounting information with the standard economic accounts, i.e. the compilation of integrated ecosystem-economic accounts. The compilation of such accounts is relevant for the derivation of degradation adjusted measurement of national income, the measurement of national wealth in extended balance sheets, and to support the incorporation of ecosystem services into extended input-output and other economic models and the measurement of other macro-economic indicators such as environmentally-adjusted measurement of multi-factor productivity. Issues associated with the compilation of integrated ecosystem-economic accounts are described in Chapter 8.

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

2.32 Four key thematic accounts are described in Chapter 9 being for land, water, carbon and species-level biodiversity. The information from these accounts will be of direct relevance in the compilation of ecosystem accounts, particularly from the perspective of supporting consistency in measurement across different ecosystem types, for example by providing 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 also likely to be of direct relevance in supporting discussion for specific policy themes including land management and planning, water resource management, management of carbon stocks and greenhouse gas (GHG) emissions and biodiversity.

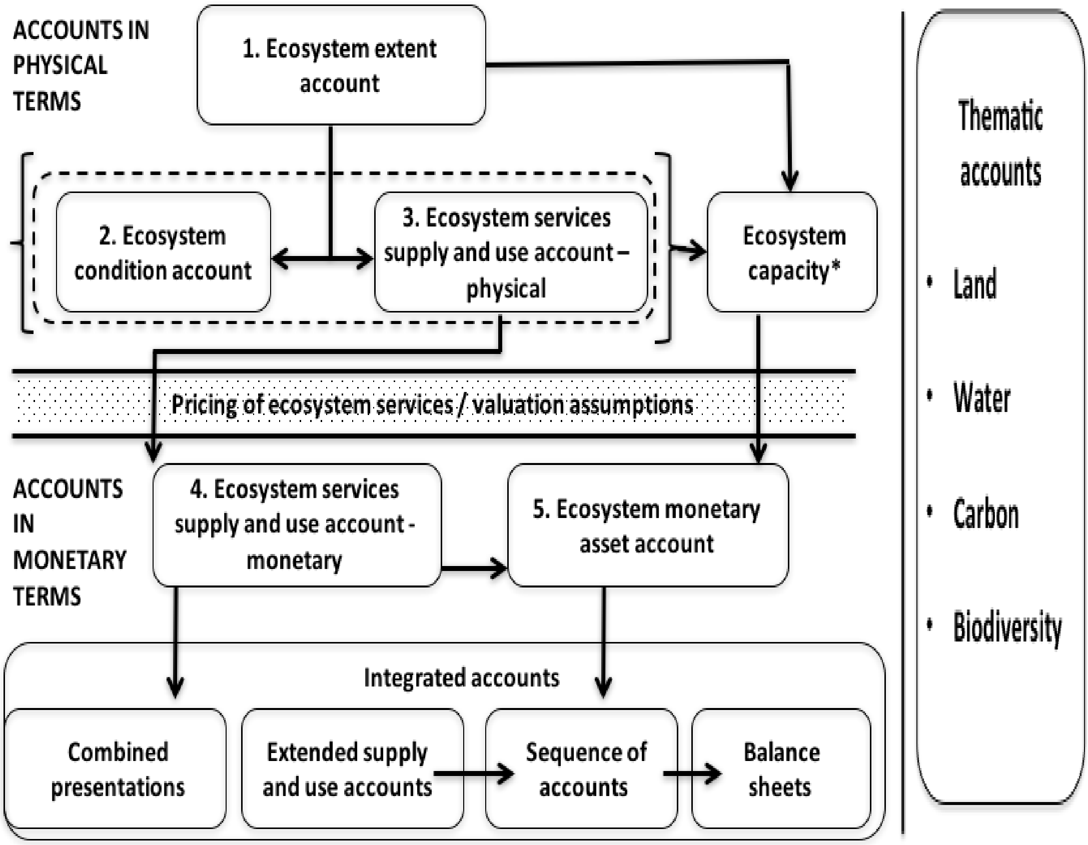
2.33 In addition, to these two accounting connections, an important concept not portrayed directly in the set of ecosystem accounts listed above is ecosystem capacity. Ecosystem capacity reflects the ability of an ecosystem to sustainably generate an ecosystem service under certain assumptions (see section 7.3 for details). It underpins the measurement of the valuation of ecosystem assets since the asset life of an ecosystem will be directly related to changes in its capacity. In effect, the concept of

[9] Following the CBD definition, 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 has not been a focus of ecosystem accounting to this point.

capacity can serve to integrate measures of ecosystem condition, ecosystem services and ecosystem degradation. An account for ecosystem capacity has not yet been developed but ongoing advances in conceptualising ecosystem capacity are discussed in Chapter 7.

2.34 The connections between the various ecosystem accounts and to these related accounts and concepts are shown in Figure 2.2. The following logic is presented. The ecosystem extent account is shown as providing a starting point for compilation. The compilation of the ecosystem condition account and ecosystem services supply and use account is shown as a concurrent exercise (depicted using the dotted line). The combination of information from these accounts feeds the measurement of ecosystem capacity. There is no stand-alone ecosystem capacity account. Using relevant valuation techniques, the compilation of monetary supply and use accounts and asset accounts can be undertaken and this information feeds into the compilation of integrated accounts. The thematic accounts are shown to provide information to support 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 compilation steps can be undertaken depending on the analytical and policy questions of focus and the data available.

Figure 2.2: Connections between ecosystem and related accounts and concepts



*Ecosystem capacity is not measured in terms of an account at this stage. The figure shows conceptually where capacity measures are situated.

2.4 The steps in compiling ecosystem accounts

2.4.1 Introduction

2.35 Ecosystem accounts can provide information that is relevant in a range of policy and analytical contexts. However, in the initial development and testing phase, it will likely be necessary to understand a more limited number of specific purposes or questions for which ecosystem accounts might be compiled. The type of policy question will help determine the scale of the accounts, either national or sub-national (e.g. water catchment, province, habitat type, etc.), and the type of data needed. Over time, and building on the initial testing, the development of a more complete set of national level ecosystem accounts can be envisaged through progressive development, extension and integration. Further, the development of an initial set of ecosystem accounts is likely to spark 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 a matter of discussion among the institutions involved in compiling the accounts. It will also be necessary to determine the relevant reference period/s for the accounts. Multiple data sources will need to be brought together to compile the accounts and hence methods of adjusting different source data to a common reference period/s will need to be adopted.

2.37 It is anticipated that the content of the Technical Recommendations will support the discussion required to make these choices, although it is recognised that other factors (such as the availability of resources) will need to be taken into account. Following the general principles of SEEA implementation (see SEEA Implementation Guide (UNSD, 2013)), the discussions should involve all relevant stakeholders, including policy makers, data analysts, account compilers and source data holders. These discussions can be very usefully supported by diagnostic tools that have been developed for such purposes.[10] As well, there can be significant benefits in establishing a senior level steering committee and associated multi-stakeholder working or technical groups. Note that the information in the Technical Recommendations is appropriate for discussions on both the commencement of pilot studies and the establishment of national programs of work.

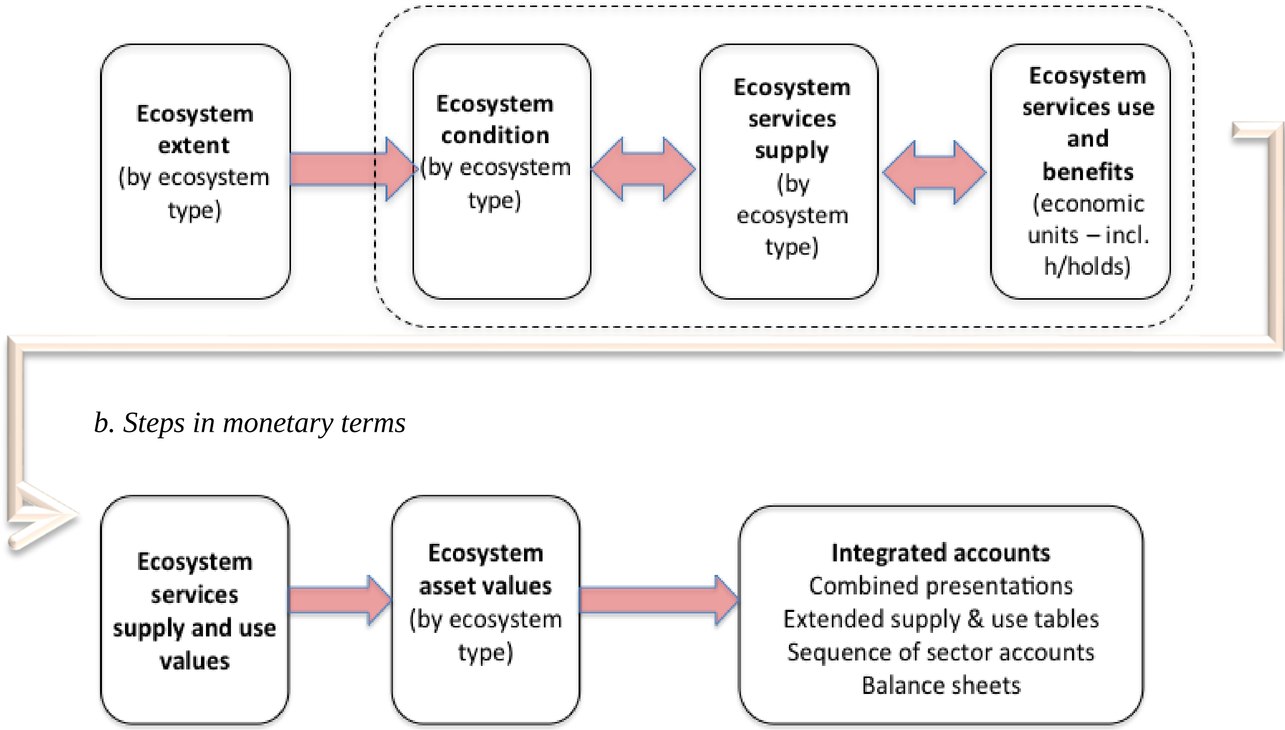
2.38 The conceptual framework for ecosystem accounting shown in Figure 2.1 provides a general description of the relationships between the different stocks and flows, and the connections between the accounts shown in Figure 2.2 provide a sense of the overall accounting picture. This section provides an overview of the steps involved in compiling ecosystem accounts.

2.39 The broad steps in ecosystem accounting are shown in Figure 2.3. The first set of steps involves accounting in physical terms and the second set of steps is in monetary terms. While it is useful to see this sequencing, the reality of accounting is that there will be multiple iterations through the accounts and further, that the precise starting point may vary. These iterations will reflect both the use of multiple data sources and the aim of providing a consistent picture from them. While ecosystem accounts are unlikely to convey the full richness and complexity of ecosystem relationships, they should provide a strong organising framework for considering the information as well as providing the means of conveying the key messages for policy and analytical discussion.

[10] 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

a. Steps in physical terms



NB: The dotted line around the boxes for ecosystem condition, ecosystem services supply and use indicates that measurement of these aspects may often be completed concurrently, and iteration between them is appropriate in developing a single best picture. Also, while the figure indicates a progression from physical to monetary, 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 in 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 will be 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 will be 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 applied, 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 below. The table illustrates that there is a continuum between a minimum application of spatial analysis in order to produce aggregated accounts, and a fully spatial approach that involves the production of both accounting tables and maps for all accounts produced, recognising that the compilation of tables and maps is not only for presentational purposes but will provide insight for compilers and analysts in evaluating the data and understanding relevant structures and trends.

2.42 When a fully spatial approach is used, there are additional policy applications compared to a minimum spatial approach, noting that not all possible applications are listed in the table. It is important to recognise that even though the approaches are distinct, the different approaches use the same ecosystem accounting framework. The differences in measurement will thus lie in the availability and choice of data sources which will have differing levels of spatial detail, the need for and extent of modelling that is undertaken, and in the nature of assumptions that are made in deriving aggregate measures.

Table 2.2: Spatial analysis in ecosystem accounting

Complexity of spatial 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 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[1] 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 policies) Support to Environmental impact assessment and Environmental cost-benefit analysis
	Partial spatial account	Maps are produced only if necessary for the analysis of specific ecosystem extent, condition or services indicators.	Data may be reported by spatial unit, by administrative unit, or by 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/very few maps produced	Data produced for each administrative unit, without consideration of spatial heterogeneity within these 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, it may be decided to use this system instead of compiling an alternative ecosystem condition account. For instance, the Norwegian Nature Index (Certain and Skarpass, 2011) is a comprehensive approach to measuring ecosystem condition. It considers the spatial distribution of species occurrences in Norway and provides an index value for species-level biodiversity for the smallest administrative unit in Norway, i.e. the municipality. The index would therefore represent an example of a 'partially spatial' approach.

2.4.2 Summary of compilation steps for developing the full set of accounts

2.44 Within the general considerations noted above, the following paragraphs describe the main steps that will be relevant following a spatial measurement pathway. Where a minimum spatial approach is pursued, it may be possible to prepare monetary accounts following the pathway laid out in figure 2.3b, commencing in Step 4 (i.e. the 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 principal be obtained without compiling ecosystem extent and condition accounts provided suitable assumptions are made about the likely changes in the physical characteristics of ecosystem assets (e.g. by assuming a fixed asset life).

2.45 Step 1: For ecosystem accounting, the first important step is to delineate the area for which the accounts are compiled, the EAA. The EAA may cover the entirety of a country's land area (including inland waters) and, as appropriate, relevant coastal and marine areas – perhaps extending to a country's exclusive economic zone (EEZ). Chapter 3 discusses the issues of delineating and classifying ecosystem assets for ecosystem accounting purposes. Thought should also be given in this first phase to the data infrastructure requirements noting that a fully spatial approach will be more demanding in terms of computing capacity and data storage, as discussed in Chapter 3.

2.46 Information on the area of an EAA can be presented in an **ecosystem extent account**. A key aim with this account is to measure the change over time in the composition of ecosystem types within a country. The ecosystem extent account is described in Chapter 3 and a discussion of the related land accounts is in Chapter 9.

2.47 Step 2: Using the listing of ecosystem types determined for the ecosystem extent account, the next step is to compile the **ecosystem condition account**. Note that this step may be undertaken following steps 3a and 3b and in any event, as indicated by the dotted line in Figure 2.3, the measurement of ecosystem condition should take into consideration relevant flows of ecosystem services. Chapter 4 discusses the compilation of ecosystem condition accounts in more detail. Chapter 9 discusses the compilation of information on land, carbon, water and biodiversity using accounting approaches since these data may be relevant in monitoring the condition of many ecosystems.

2.48 Step 3: The next step involves the measurement of **ecosystem services in physical terms**.[11] This is completed 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 those described in Chapter 5. A classification can provide a checklist to ensure appropriate coverage.

2.49 A common way of thinking about the supply of ecosystem services 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. This thinking is reflected in Figure 2.1. This is certainly true for some ecosystem services, mainly provisioning services where materials are harvested or extracted from a given ecosystem asset (e.g. timber from a forest or water from a lake). However, for a number 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 to provide flood protection will involve contributions from forests, grasslands, and other ecosystem types within a flood plain. While it is possible to estimate the contribution of different ET to the provision of an individual service (e.g. the relative contribution of forests to water regulation), the starting point for measurement is likely to be best considered in terms of an individual service rather than a single ET.

2.50 Step 3 should encompass estimation of both the supply of ecosystem services and the use of those services by various beneficiaries. Together, the information on supply and use are used to compile an **ecosystem services supply and use account**. To support integration with the national economic accounts, the beneficiaries in

[11] In this context, "physical" means "non-monetary" and 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. (SEEA EEA para 3.2)

ecosystem accounting are grouped in the same way as for the economic accounts – i.e. by industry group and by institutional sector. The possible approaches to measurement are discussed in Chapter 5.

2.51 Step 4: Here the focus is on the **valuation of ecosystem services** in monetary terms. There are many examples of the valuation of ecosystem services and it is a necessary step for certain types of integration with the standard national accounts, such as adjusted GDP and extended measures of net wealth. The valuation of ecosystem services supports the compilation of **ecosystem service supply and use account in monetary terms** and also the **ecosystem monetary asset account** and measures of ecosystem degradation. The measurement of ecosystem degradation requires an assessment of ecosystem capacity which reflects the connection between ecosystem condition, ecosystem extent and ecosystem services.[12] The valuation of ecosystem services is discussed in Chapter 6 and the compilation of ecosystem monetary asset accounts and estimation of ecosystem capacity is described in Chapter 7.

2.52 Step 5: The final step involves the use of information on ecosystem services, ecosystem assets and ecosystem degradation from the accounts described above, to integrate environmental and economic data and augment the current, standard national accounts. As discussed in Chapter 8, this may be done in a number of ways including:

i. The compilation of combined presentations where data on ecosystem condition and services in physical terms are presented alongside standard economic data, such as value added, employment, or costs of environmental restoration.

ii. The full extension of the ecosystem services supply and use accounts in monetary terms to also include all products. This approach can be used to show the integration of ecological and economic supply chains.

iii. The compilation of an extended sequence of accounts where 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 institutional sector and industry.

iv. The estimation of a national balance sheet in which the value of ecosystem assets is incorporated with the value of other assets and liabilities to derive extended measures of national wealth.

2.53 In undertaking these different steps, under either fully spatial or minimum spatial approaches to measurement, it should be understood that the logic of the approaches is consistent with the types of approaches used for the compilation of national accounts. National accounting measurement has 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 summarised in Annex 2. This annex 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 understanding the set of ecosystem accounts as presented in the Technical Recommendations.

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

2.55 First, as far as possible, the accounts are designed as a system of accounts such that information can be readily compared between accounts. Thus, while there is more than one account, and each account can stand alone, there are relationships between the accounts that can be highlighted by structuring the information appropriately, recognising that, in practice, the connections between ecosystem service flows and ecosystem assets are difficult to define and measure.

2.56 Second, a very specific design feature of the ecosystem accounts is that ultimately the information should be able to be integrated with the standard national accounts that record economic activity. This design feature does not impact on all accounts but is particularly relevant for accounts concerning ecosystem services and accounts compiled in monetary terms.

2.57 Third, the accounting structures presented should not be considered unchangeable with regard to the level of detail they contain. For example, the accounts concerning ecosystem condition, described in detail in Chapter 4, are structured according to broad ecosystem types (e.g. grasslands). In practice, it may be most relevant to provide finer detail for some specific ecosystem types (e.g. by type of grassland). Such rearrangements of information are perfectly appropriate and 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. Most commonly, the interest in accounting information stems from the presentation of time series of information, i.e. for multiple accounting periods. The duration of an accounting period can be altered, for example to develop sub-annual accounts which may be relevant for some purposes such as seasonal analysis of ecosystem services related to water.

2.59 Presuming that a time series of accounts is compiled, users of accounting information are likely to require a re-organisation of the information such that time is one of the dimensions presented in the accounts. In practice, this is an issue of data management and dissemination rather than of concept. Compilers should feel free to restructure the accounts described here in such a way to best suit the presentation and analysis of data, in reference to the associated policy questions and the needs of users.

2.60 Fifth, the structure of accounts will generally represent a level of detail suitable for presentation and analysis of outputs from accounting. It represents the level of detail at which accounting relationships (e.g. supply and use, balancing end of period stocks and changes in stocks) are applied. However, it will generally be necessary for underlying information to be organised at different, usually lower, levels of aggregation before entry into the accounts.

2.61 In the case of ecosystem accounting, for spatial approaches it is likely to be ideal to compile data at an appropriately detailed level using a common spatial data infrastructure and then aggregate to the relevant ecosystem type level for accounting purposes. This does not require that ecosystem accounts are compiled at fine levels of detail but rather that the input (or source) data and the output (or disseminated) data are managed distinctly.[13] Indeed, making this 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. Changes to input data, including changes to classifications, should be considered a normal and common feature of accounts compilation.

[13] The term “reported” data is commonly used. For most non-statisticians, this term relates to output or disseminated data however for statisticians it relates to data collected or reported that is used to form statistical estimates. Given the divergent use of the same term, it is not used in these Technical Recommendations.

2.62 For some input data sources, detailed spatial information will be a feature, for example for 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 will require additional work. For data sourced from official statistical sources, it would commonly be necessary to downscale aggregate data using allocative techniques. The development of geo-referenced statistical information may be a useful input to this process. For administrative data sources data may be available for specified sub-national areas but adjustment may be needed to align 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 these data and associated relationships can be applied in other areas. 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 socio-economic surveys. The particular challenge for ecosystem accounting is finding the correct levels of stratification of environmental features (e.g. vegetation types, climate, elevation, etc.) such that observations can be appropriately scaled. There is a range of approaches to benefit transfer for ecosystem measurement. An introduction is provided in SEEA EEA Chapter 5 and there are several papers in the scientific literature that provide further insights, such as Plummer (2009).

2.64 Sixth, a general ambition in the implementation of ecosystem accounting is to facilitate the comparison of information on ecosystems within and between countries. The ability to compare information can be an important basis for the discussion of policy and can support analysis and data exchange. This is especially relevant with respect to transboundary environmental stocks and flows such as water and migratory species. The rationale for 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 focus is not on ensuring that there is commonality in method, since differences in method will likely be appropriate in different contexts.

2.65 At this stage in ecosystem accounting there is good progression towards an agreed framework recognising of course that more discussion and testing is needed. There is far less revealed agreement or commonality in methods for ecosystem accounting. In part, this is due to the quite different applications of the ecosystem accounting framework which naturally leads to the use of different methods and data sources that are fit for purpose. It also reflects the breadth and variety of connections between ecosystems and people that need to be taken into account.

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

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

3 Organising spatial data and accounting for ecosystem extent

Key points in this chapter

Ecosystem accounting requires the delineation of areas within a country into mutually exclusive units that represent ecosystem assets.

Ecosystem assets (EAs) are the distinct spatial areas that form the conceptual base for accounting and the integration of relevant statistics. They represent contiguous areas covered by a specific ecosystem (e.g. a single deciduous forest).

Ecosystem Types (ETs) are aggregations of individual EA 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 countries, the number of EAs is too large to meaningfully report by individual EA, and accounts report information on ecosystem extent, ecosystem condition and ecosystem services by ET.

Accounts will generally be 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). EAA are geographical aggregations of EAs that can be grouped by ETs.

Basic spatial units (BSU), in the form of grid squares or small polygons, support the delineation of EAs and ETs and the organisation of spatial data sets for ecosystem accounting. For measurement purposes, BSUs are assumed to be internally homogenous 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 datasets should be brought together in a consistent way using the same reference coordinate system within a common spatial data infrastructure.

A key bottleneck to producing accounts is getting access to different datasets, both spatial and non-spatial, and integrating these data effectively. It is therefore important that collaboration is sought with the various agencies holding datasets required for the production of the accounts. This may be time-consuming and should be pursued in an early phase of account development.

3.1 Introduction

3.1. To provide a starting point for measurement, the SEEA EEA applies the definition of ecosystems from the Convention on Biological Diversity (CBD) – "ecosystems are a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (CBD, 1992, Article 2, Use of Terms). Ecosystems are not straightforward to delineate spatially for measurement purposes. In ecological terms, they may be defined at a range of spatial scales, and hence it is often difficult to identify clear boundaries and they may overlap in spatial terms. For statistical and accounting purposes, it is necessary to clearly differentiate ecosystem assets as discrete units. Hence, 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 have 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 such that there are no gaps or overlaps – i.e. the approach must be mutually exclusive and collectively exhaustive.

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

3.4. This chapter outlines the approach taken in SEEA EEA to organise spatial data and account for ecosystem extent, building on the discussion in SEEA EEA (Section 2.3). The framework for delineating spatial areas for ecosystem accounting is presented in section 3.2 and section 3.3 describes the ecosystem extent account, and its role as the basis for ecosystem accounting. Section 3.4 presents information on how the ecosystem extent account can be compiled. The conceptual and practical aspects of delineating spatial areas are described in section 3.5. In section 3.6 a summary of data sources, classifications and methods is provided. Section 3.7 provides recommendations for testing and areas for ongoing research.

3.5. The basic terminology and concepts related to spatial units are applicable to all approaches to the implementation of ecosystem accounting. The difference 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 only mapped and modelled where this is required to obtain the information needed to fill the accounting tables.

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

3.2 The 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 – ecosystem assets (EA), ecosystem types (ET) and ecosystem accounting areas (EAA). These areas are key elements of the ecosystem extent account and provide the basis for spatial analysis in the other ecosystem accounts. Each of these three types of areas is described in this section (see also Figure 3.1 below).

3.8. At this stage in the development of ecosystem accounting, considerable flexibility is evident in the way in which these different 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, involving ecological factors only or also taking 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). From a statistical and accounting perspective, these requirements ensure that a complete and non-duplicative picture can be described.

3.10. Second, the choice of spatial data and the associated classification of data that are used to delineate spatial areas should be sufficiently detailed to be able to reflect a composition of ecosystems across a country or EAA that is appropriate for analysis and decision making. For example, if only a limited set of ecosystem types is applied then it may only be possible to provide general messages of changes in ecosystems, while with more ETs more detailed analysis might be developed.

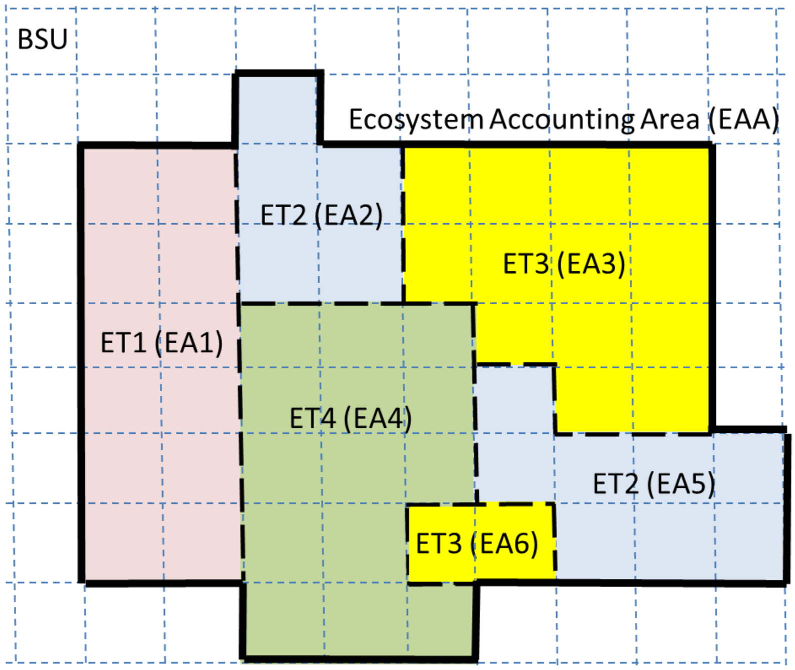
3.11. Third, for a single set of ecosystem accounts (e.g. a set of extent, condition and ecosystem services accounts) for a given ecosystem accounting area, the classification of ecosystem types that is used should be common for the different ecosystem accounts and any associated thematic accounts. Thus, 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. For different sets of accounts within a country – e.g. a set of national level ecosystem accounts and a set of ecosystem accounts developed for a specific area within a country, such as an individual water catchment – areas may be classified in different ways since the focus of accounting may be different. However, in these situations it will be appropriate to adopt a correspondence of some sort.

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

3.13. In describing a framework for the delineation of spatial areas it may appear as though the task is a relatively linear one in that spatial areas are defined, measurements are undertaken and then accounts are compiled. In practice, this linear sequence is unlikely to be the case. Rather, particularly in the initial testing of ecosystem accounting, it should be expected that a high degree of iteration takes place between (i) the delineation of ecosystem assets, (ii) the classification of ecosystem types, (iii) and the measurement of ecosystem condition and ecosystem services. Ultimately, a balance will need to be found between the data available and the intended use of the data building on an emerging understanding of the more relevant connections between ecosystems and economic and human activity. This initial work will also highlight those areas in which additional investment in data can add most value.

3.14. A stylised example of the spatial structure of the ecosystem extent account is shown in Figure 3.1. The figure also shows the relationships between EA, ET and EAA. The EAA is defined by the thick black boundary line. Six distinct EAs are delineated and these have been classified to four different ET. The figure also incorporates the basic spatial unit (BSU), the spatial unit of measurement, which is discussed in section 3.5. The BSU may correspond, as in Figure 3.1, to a grid cell in a spatial information system or to individual polygons in cases where a vector based approach to ecosystem extent accounting is pursued.

Figure 3.1: Relationships between spatial areas in ecosystem extent accounting



Source: Adapted from SEEA EEA Figure 2.4 (UN et al., 2014b). Note that Ecosystem Assets (EA) represent individual, contiguous ecosystems. Ecosystem Types (ET) are EA of the same type.

3.2.2 Ecosystem Assets (EA)

3.15. Conceptually, for accounting purposes, each area covered by a specific ecosystem type is considered to represent an ecosystem asset (EA). EAs are considered to be contiguous, and bounded spatially with each asset comprising all of the relevant biotic and abiotic components within those bounds that are required for it 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 an EA are stronger than the relationships with components outside of the EA. These differences in relationships will be reflected in differences in function, structure and composition. Hence, EAs will ideally be delineated based on various characteristics such as vegetation structure and type, species composition, ecological processes, climate, hydrology, soil characteristics and topography. These characteristics may be used alone or in combination. The choice will be dependent on the country, the ecosystems involved, the detail required for policy and analysis, and the data available.

3.17. It is also relevant to use information on ecosystem management and ecosystem use as part of the delineation of EAs. This may be particularly helpful in understanding the flows of ecosystem services that are most likely 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 is also noted that maps that delineate land within a country according to different land management regimes (for example 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 recognised that the greater the number of ecological and use characteristics used for delineation, the greater the number of EAs that will be identified.

3.18. If various data on ecological and use characteristics (as listed above) are not available, a land cover based delineation of EAs may be used as a starting point. This 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, countries should use the most refined set of land cover types available for their country to provide as close a match as possible with known ecosystem typologies. Where country specific detail is not available, the most coarse level of classification to be applied is the interim land cover classification of the SEEA Central Framework which has 15 classes as shown in Table 3.1.[14] 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. Note that 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 national boundary, the associated EAs need to be delineated with reference to the national boundary such that the aggregate of all EAs for a country is equal to the total country area.

3.2.3 Ecosystem Type (ET)

3.20. EAs are contiguous areas representing individual ecosystems. In practice, given that accounts are normally developed at aggregated scales, such as 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 type “deciduous forest”, rather than in services from individual patches of deciduous forests. Alternatively, data may only be sufficient to provide 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.

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

3.23. Ecosystem types can be interpreted as aggregations of ecosystem assets of similar type. As well, ecosystem assets can be interpreted as contiguous areas of a specific ecosystem type. In practice, a ecosystem accountant will need 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 located in floodplains provide an important hydrological service (water storage leading to reduced flood risk) whereas grasslands located outside

[14] The 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 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 the land cover classes see the SEEA Central Framework, Annex 1, Section C.

of floodplains do not provide this service. Thus, even though they have similar vegetation cover, it is helpful to attribute these areas to different ETs, thereby facilitating a coherent linkage between ET and ecosystem service supply. Similarly, ecological detail concerning the type of perennial crop, or the hydrological properties of a forest, facilitates identifying and analysing the ecosystem services supplied by those ETs.

3.25. However, as the ecosystem type classification becomes more detailed, the accuracy of the information used to identify them may reduce (depending on the data source). In practice, a balance must be found between the number of different ETs that are identified and the availability of information, noting that the use of a limited number of types will also limit the sophistication of the questions that can be answered using the accounting information.

3.26. In general, land use classifications are more specific (and have more classes) compared to land cover classifications. In the same way, classifications of ET will normally be more detailed than land use classifications (since in addition to land use also the types of ecosystem services are considered; even with similar uses these services may differ because of, e.g., hydrological properties as mentioned above).

3.27. Specifying ETs requires consideration of land cover, land/ecosystem use and ecosystem services provided, the latter reflecting a function of 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. It is recommended to only consider selected (typically less than five) ecosystem services and how they are supplied by different ecosystems in the classification of ETs based on land use. For example, in low lying areas, services related to flood control may be of high interest, in dry areas, services related to sustaining water flows may be of high importance, and in mountains there may be areas that are essential for erosion control (e.g. headwaters and riparian vegetation) that merit their inclusion as specific ET.

3.28. Table 3.1 provides an initial example of ET types and illustrates the difference between land cover and ET. It shows that ETs are typically nested within land cover classes thus recognising that differences in ecological characteristics are a prime consideration in differentiating between ETs. Note as well that there is important similarity between classes often defined in land use classifications and ETs. Generally, only when land use classes provide distinctly different baskets of ES it is useful to separate them into different ETs.

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 will be appropriate to distinguish specific ecosystem types within the land cover class ‘coastal ecosystem’ (e.g. seagrass meadow, coral reef, oyster/mussel bank, mangrove, rocky substrate, sandy substrate, etc.). In the land cover class ‘marine ecosystems’ there may be potential to differentiate between, for example, reefs, sandbanks, continental shelf and deep sea.

3.30. There have also been, as yet, relatively few projects focusing on accounts for urban ecosystems. Tentatively, it seems appropriate that in the case of urban ecosystems various ecosystem types can also be differentiated based on the combination of cover, use and the services they supply. This may include, for instance, urban parks within city boundaries, different types of parks nearby cities but outside residential zones, and perhaps even specific areas such as rivers flowing in urban areas, river beds, canals or cemeteries.

Table 3.1: Initial example of land cover classes and ecosystem types

Description of land cover classes (SEEA Central Framework)	Possible ecosystem types
Artificial areas (including urban and associated areas)	Residential/housing Urban parks Industrial uses (e.g. factories) Road infrastructure Waste deposit sites
Herbaceous crops	Irrigated rice Other irrigated crops Rainfed annual croplands
Woody crops	Fruit tree plantation Coffee and tea plantation Oil palm plantation Rubber plantation
Multiple or layered crops	Two layers of different crops (e.g. wheat fields with 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)
Grassland	Natural grasslands Improved pastures Steppe Savanna
Tree-covered areas (forests)	Deciduous forest Coniferous forest Plantation (planted) forest
Mangroves	Inland mangroves Nearshore mangroves
Shrub-covered areas	Natural dryland shrubland Degraded dryland shrubland
Shrubs, and/or herbaceous vegetation, aquatic or regularly flooded	Wetland shrubland
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	

Source left-hand column: SEEA Central Framework Table 5.12 (UN et al., 2014a).

3.2.4 Ecosystem Accounting Area (EAA)

3.31. Conceptually, it is possible to develop a set of ecosystem accounts for an individual EA, such as an individual forest, wetland or farming area. This 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. for all grasslands in a country). However, the general ambition of ecosystem accounting in the SEEA is to provide more general guidance as to the changes in ecosystem related stocks and flows in larger and diverse spatial areas.

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

3.33. At the most aggregated levels, this involves accounting at the national or in particular cases at the continental level[15], i.e. covering all EAs within a country or group of countries. However, it will commonly be appropriate to create aggregations of

i. EAs and ETs within specific sub-national administrative areas

ii. EAs and ETs within hydrologically defined areas within a country (such as water catchments)

iii. other areas of policy interest such as protected areas, or areas owned by specific industries or sectors, e.g. government owned land.

3.34. Commonly, these aggregations will reflect contiguous areas, such as administrative areas or river basins, but this is not a requirement for accounting purposes. The geographical aggregation for which the account is developed is labelled the ecosystem accounting area (EAA).

3.35. Within each EAA there will be multiple EAs of different ETs, e.g. individual EAs of forests, wetlands and cropland. The resulting accounting structures, as introduced in Chapter 2, will generally be 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 sub-national administrative area, an ecosystem extent account would show the changing total area of each ET (e.g. forest, wetland, cropland). It would not show the changing area of each individual EA.

3.36. A single EA may be classified to multiple EAA, for example to an EAA formed as using a water catchment and also to an EAA formed using an administrative region. Incorporating a single EA into different EAA will be relevant depending on the question being addressed.

3.3 The ecosystem extent account

3.37. The most common starting point for ecosystem accounting is organizing information on the extent of different 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 the SEEA Central Framework with an opening extent (in hectares or km^2), closing extent, additions and reductions. The columns reflect the chosen classification for ecosystem types. The proposed structure here uses high level ecosystem types based on the interim land cover classification in the SEEA Central Framework. Additional sub-classes may be added depending on the ecosystem types of most relevance within a country. An example of more detailed sub-classes is shown in Table 3.1 (above).

3.38. Where the type of land cover is the only characteristic used to delineate different ecosystem assets, then a land cover account and an ecosystem extent account will be the same. Where additional characteristics are used to delineate ecosystem assets, different results would be expected.

[15] As in the case of the European Union ‘KIP INCA’ project described in Annex 1.

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 inter-tidal areas	Sea and marine areas	TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Opening extent																
Additions to extent																
Managed expansion																
Natural expansion																
Upward reappraisals																
Reductions in extent																
Managed regression																
Natural regression																
Downward reappraisals																
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[16]. Hence the total area recorded in the right-hand column should be the same for the opening and closing stock and should remain unchanged irrespective of the number of different ET that are introduced into the table. Where the total land area does change, for example, due to land reclamation, the compiler should record the change against the relevant addition or reduction following the advice in the SEEA Central Framework, section 5.6.3. Changes in area due to political factors should be recorded as upward or downward reappraisals.

3.40. In the ecosystem extent account presented in Table 3.2 there is no requirement that the areas of each type of ecosystem be contiguous. That is, the total area of, for example, grassland, will occur in various EAs across a country and the data in Table 3.2 represents an aggregation of all of the different EAs.

3.41. Information from an ecosystem extent account would be usefully presented in maps using different colours for different ET. Mapping the information can more readily highlight issues of fragmentation of ecosystem types and possible connections between ecosystem types that are not apparent when the information is presented in a traditional table format.

3.4 Compiling the ecosystem extent account

3.42. The ecosystem extent account is the basis for ecosystem accounting. It will usually be the first ecosystem account to be developed. When compiling the ecosystem

[16] Accepting that there may be seasonal or other regular variations in area in some coastal ecosystems.

extent account the main challenges are to make informed choices on the ETs to be distinguished and the resolution (and minimum mapping unit) of the maps. The starting point will usually be 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 requirement is to determine how information in these maps can be combined to produce an ecosystem extent account and map that reflects the composition of ET. Based on these information sets it needs to be decided if a raster or a vector based approach to producing the ecosystem extent account is used, see also section 3.5 below.

3.43. In addition, in particular when accounts are produced for smaller areas, it may be decided to fill the accounts with more detailed information for individual EAs. This increases the resolution at which data on ecosystem services flows and assets needs to be compiled.

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

3.45. In many countries, cadastres are well established, i.e. administratively defined areas that are delineated on the basis of land ownership. Information from cadastre-based datasets can be linked to information on EAs, ETs, economic activity, land use and other socio-economic information. For instance, it is possible to combine information on land ownership (tenure) with ET and water catchment information to understand the 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 to policy initiatives, particularly in those countries where land is under private ownership. However, it is not recommended that land ownership data be directly applied to delineate EA since this information may raise sensitivities in many countries. Furthermore, depending upon the size of the cadastres, it may be common for a single cadastre to comprise multiple EA.

3.5 Spatial infrastructure, measurement, and data layers

3.5.1 Basic spatial units (BSU)

3.47. While EA, ET and EAA represent the spatial areas for accounting and statistical purposes, for many ecosystem measurement purposes there is a need for a spatial measurement unit as a basis for constructing the accounts. For ecosystem accounting, this spatial unit is termed a basic spatial unit (BSU). A BSU is a small spatial area that is a geometrical construct. The purpose of BSUs is to provide a fine level frame to which a range of different information can be attributed. The precise definition of BSUs will depend on the context and the nature of the approach taken to managing spatial data for accounting.

3.48. To develop a spatial data infrastructure for accounting, it is first necessary to select and set-up a soft and hardware environment integrated into a Geographical Information System (GIS). This will usually involve 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 necessary that all spatial data layers, whether containing raster (grid) or vector data, are converted to the same reference coordinate system for analysis. Countries generally have a specific reference coordinate system, and the ecosystem accounts can use either this system or a global reference coordinate system (such as WGS 84).

3.50. When global datasets are used to complement national data, it needs to be verified that all datasets use the same reference coordinate system, and if not, spatial data should be corrected for this (by using standard procedures in GIS involving the connection of spatial data to the selected reference coordinate system).

3.51. Of relevance also, is the projection system that is used to transfer the three-dimensional earth surface to a two-dimensional spatial data layer. When grid shaped BSUs are part of the spatial data infrastructure, normally an equal area projection is recommended in order to ensure that all grid cells have the same size.

3.52. With this infrastructure in place, the datasets to be used for the accounts can be integrated in the selected spatial data environment. Typically, ecosystem accounting involves the integration of data from national accounts, surveys and spatial data from different sources (including from thematic maps and remote sensing data). Spatial data is usually available at different resolutions (thematic maps often use polygons, remote sensing data may be available at 30m grid (LandSat) or, increasingly, at 10m grid (Sentinel 2)). In order to fill data gaps, where appropriate data can be interpolated and extrapolated to establish wall-to-wall maps (i.e. no missing or undefined cells) of relevant variables for the different accounts.

3.53. In defining BSUs and analysing spatial data, a flexible approach is proposed in recognition of the large differences across countries in terms of spatial area, ecological heterogeneity and data availability. A fundamental choice in setting up the spatial data infrastructure is whether to use a reference grid and use this reference grid to integrate all data layers, or to allow different datasets to have different formats (grid or vector) and/or different grid sizes.

3.54. A reference grid approach should be understood as an approach where a reference grid is established with single reference coordinate system and with an agreed grid size, for example, 100 by 100m. Then, for all data layers, data are attributed to the reference grid cells ensuring that for every data layer there is a specific value for each reference grid cell. Such an approach has the advantage that it reduces the amount of data involved and the complexity of the spatial modelling.

3.55. Where a reference grid is established, a key question is what size the grid squares should be for ecosystem accounting purposes. There are three main considerations in the selection of the grid size. First, the resolution at which data are available. Second, the spatial variability of the ecosystems within the EAA. Third, the potential limitations on computational capabilities and data storage. For example, an EAA with many small landscape elements such as forest patches and hedgerows will require a finer (smaller) grid compared to EAAs with large-scale landscape elements such as large savannah areas.

3.56. In general, it can be recommended that grid sizes of 25 to 100m typically be considered a good starting point for accounting purposes, but note that larger grid sizes may be appropriate where accounting is undertaken at the continental scale. Grid sizes down to 10m and smaller are now possible in some countries, but whether delineation at that level of detail is required or appropriate for ecosystem accounting should be informed by the use of the accounts for decision making. The use of a single reference grid generally reduces the accuracy of (some of) the data. Further, the larger the grid squares, the higher the inaccuracy that is introduced by converting individual data layers to the reference grid.

3.57. Where a reference grid is established, each cell in the reference grid represents a BSU. In this approach, a range of information is attributed to each BSU, including for example details of EA, ET, land cover, soil type, elevation and other biophysical and/or socio-economic information.

3.58. The alternative to using a reference grid, perhaps more appropriate for smaller EAAs, is to include spatial datasets with different resolutions (for instance a combination of relatively coarse vector-based thematic data, a more detailed vector-based topographic dataset, ecosystem condition indicators sampled with remote sensing imagery of 30m resolution and other ecosystem condition indicators sampled at 10m resolution). Provided a consistent reference coordinate system is used for all data layers, these different datasets 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 datasets 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 either using a raster or a vector based approach. As noted, this 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 datasets will typically be in vector format. Note that the use of a vector format is particularly relevant for the analysis of linear and point elements in the landscape, in particular for elements which may not be covered accurately using a raster map, such as roadsides, hedgerows, streams or individual trees (in an urban context).

3.60. Further, where no reference grid is used, each data layer may have its own specific resolution. In this case, the BSU represents the smallest spatial unit underlying the ecosystem extent account, which as noted may either be in a raster on in a vector format. Note 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 BSU represents one EA.

3.5.2 Data layers and delineation

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

- Land cover and land use from either existing maps and referenced point data or based on additional remote sensing imagery
- The topography of the country (coastline, digital elevation model (DEM), slopes, river basins and drainage areas)
- Vegetation type and habitat type
- Species composition
- Hydrology (river and stream networks, lakes, groundwater flows and aquifers)
- Soil resources and geological 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 have only been partially populated, i.e. the spatial cover of the data does not extend to the full EAA, or it involves geo-referenced point data rather than maps. In these 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 inter- and extrapolated, to ensure consistent coverage and reporting. Various spatial interpolation tools such as inverse distance weighting, 'kriging' or maximum entropy modelling may also be used for this, see for example Schröter et al. (2015) or Willemen et al. (2015), as well as paragraph 3.74 below. The appropriate approach for populating data layers should consider the type of data and experience of experts in the specific measurement area.

3.63. With these data sources and tools in place, there is a range of choices available for delineating the spatial units needed for ecosystem accounting, depending 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 above.

3.64. First, there is no standardised method for delineating EAs. However, it needs to be considered that when the ecosystem accounts are developed for a (part of) country, it is important to build upon existing environmental and other datasets. This allows efficient use of available data, facilitates the integration of datasets and avoids producing partially overlapping datasets. Countries will 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 EAA and the diversity of ET, the compilers of the ecosystem accounts may decide to delineate individual EAs or instead work on the basis of ETs.

3.65. In delineating EAs, wherever possible, it is recommended that initial focus is on ecological principles since EAs are considered 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, as discussed above, it will also be 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 its importance in flood control and water management. Flood plains may have similar land cover (mostly grasslands) as other ETs (e.g. pastures), but the type was identified based on distinctive hydrology and services supplied (i.e. water regulation).

3.66. For the integration of ecosystem information with socio-economic data, a potential choice for EAA are nationally defined statistical areas. Statistical areas will also commonly correspond best to the level of coverage of government decision-making. Depending on the decision-making context, other boundaries will also be relevant including state, province, municipality (specific data may be available from national accounts for these 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 will be required.

3.6 Recommendations for developing a National Spatial Data Infrastructure (NSDI) and the compilation of ecosystem extent accounts

3.6.1 Developing an NSDI

3.67. Based on the framework described in this chapter, a number of points emerge as being steps that countries can focus on in testing and experimentation in ecosystem accounting. A theme in these recommendations is that work to establish the spatial areas required for ecosystem accounting is best undertaken within a broader context of work, already completed or planned, to establish a national spatial data infrastructure (NSDI) that would support integration of environmental and socio-economic data. The INSPIRE project is an example of this type of direction.[17] It should be recognised that (i) an NSDI is not essential to commence work on the compilation of ecosystem accounts and (ii) that there are many additional issues in the establishment of an NSDI than presented here. In this broader context, the advances occurring through the UN GGIM project are of particular importance as are numerous efforts underway at national level.[18]

3.68. The starting point in utilising an NSDI for ecosystem accounting is an inventory of what spatial data infrastructure already exists in a country, in particular within government agencies such as spatial planning or environmental agencies. This assessment should include documenting the most commonly used GIS software packages and the available datasets. Where feasible, the development of a spatial data infrastructure for accounting should build upon existing infrastructure.

3.69. Relevant elements to consider in building upon an existing, or establishing a new spatial data infrastructure include, but are not limited to, the coordinate and spatial projection system, and whether a reference grid will be used. A reference grid may be most relevant in case of large areas, large datasets, and restrictions in computing capacity. If a reference grid is used, the size of the grid cells needs to be established. Note that resolution is not equal to grid size. Resolution relates to the smallest objects visible in an image or map, grid size is the on-the-ground area covered by a pixel. Objects need to be larger than grid size to be visible in an image.

3.70. Another consideration in setting up the spatial data infrastructure is the minimum mapping unit (MMU), i.e. the minimum size that a contiguous area needs to have to be distinguished in the map. Usually, an MMU substantially exceeding the grid size is chosen to facilitate interpretation of the map.

3.71. The development of spatial data infrastructure also requires selecting hardware with sufficient processing, storage and back-up capacity, and GIS software.[19]

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

- Official boundaries, including country, administrative, statistical, river basins, biogeographic areas, shorelines, etc. (as polygon vector data)
- Elevation and topography data, based on a digital elevation model (DEM). If no detailed country-level data are available the global ASTER dataset[20] can be used. The DEM data are important to distinguish the elevation and slope of the BSU.
- Land cover data
- Additional data layers as available including

[17] See https://themes.jrc.ec.europa.eu
[18] See http://ggim.un.org/UN-GGIM-Thematic-Groups/
[19] Free and open source software, such as Quantum GIS, or commercial - ArcGIS
[20] http://asterweb.jpl.nasa.gov/gdem.asp

    - Land management/use
    - Vegetation type
    - Soil and geology data
    - Hydrological data related to rivers, lakes, streams, coastal and marine areas
    - Data on urban infrastructure, including cities, villages, industrial zones, and transport (rail, road), that is needed for assessing ecosystem condition and understanding ecosystem use (e.g. relevant for mapping fragmentation and other impacts)
- Socio-economic data including population data, employment, economic activity, etc.

3.73. As part of the development of an NSDI and, ultimately a national register or listing of ecosystem assets, it will be important to understand 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 nature conservation/protected areas. In some cases, these existing spatial boundaries may provide a suitable starting point for ecosystem accounting.

3.74. Further, it is appropriate to develop an understanding of the hierarchy of ecosystem/landscape/eco-region/biome units that are relevant for the country. This can be done in reference to existing products (e.g. World Wildlife Fund (WWF) eco-regions, or the ESRI/USGS global ecosystems map (https://rmgsc.cr.usgs.gov/ecosystems/). Overall, testing and experimentation should reveal what are 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.

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

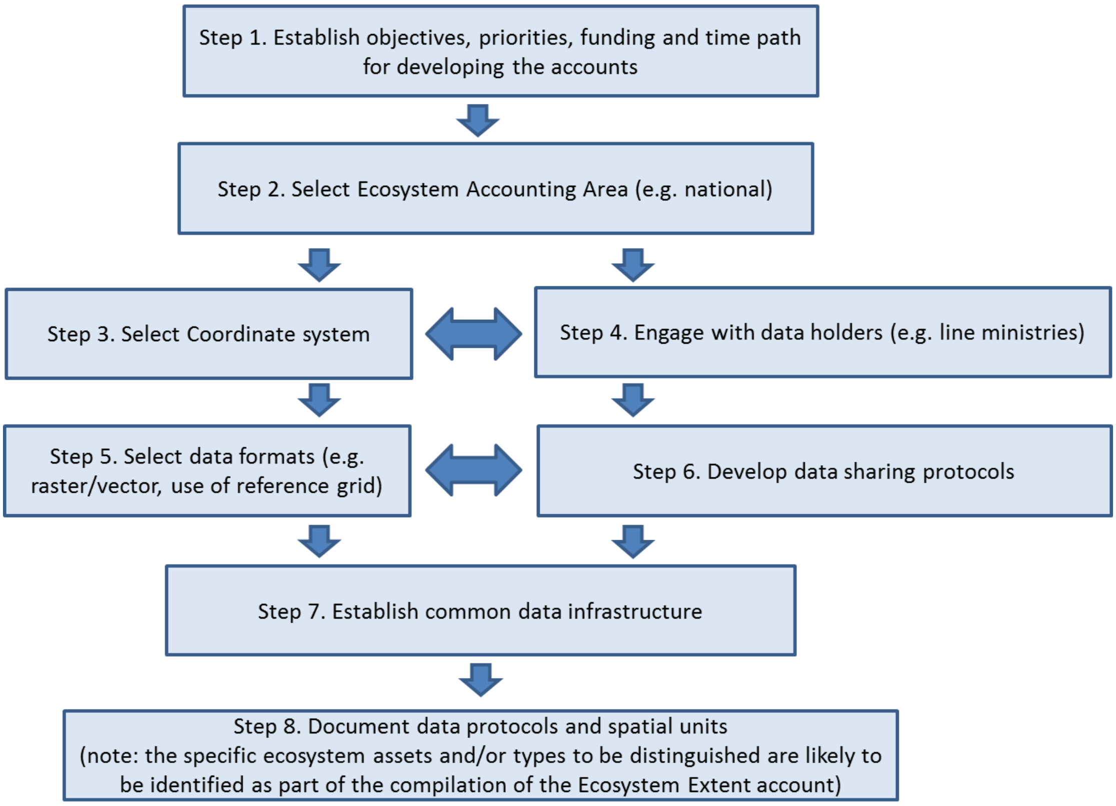
3.76. A critical aspect in developing the accounts is the need to establish data sharing arrangements and agree on data access with all the data holders. Data sharing and capacity are the key bottlenecks, even more than the availability of data. It is recommended that, given the amount of time it may take to establish data sharing arrangements, this is one of the first priorities in the development of an NSDI. In the development of the NSDI it is recommended to consider the data formats including the reference coordinate systems used by the various agencies and to assess if similar formats and coordinate systems can be aligned within an NSDI.

3.6.2 Recommendations for developing the ecosystem extent account

3.77. It is likely that in most cases, application of the SEEA EEA will start with developing the extent account. The compilation of this account will be best conducted using an NSDI. The key steps in developing a spatial data infrastructure for ecosystem accounting are depicted in Figure 3.2 below. The figure shows that a first priority is to establish objectives, priorities and a time path for the compilation of the accounts, including the development of the NSDI, and then to select the ecosystem accounting area for which the accounts will be developed. The ambition level of the account will determine the relevant territory and the resolution at which data will need to be generated. In turn, this will 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 for large countries or at a continental scale, additional computing power, either deploying a server or computing and data storage 'in the cloud' may be required.

3.78. A key step in compiling accounts is the development of protocols for data sharing with data holders. This may be time consuming and needs to be planned well in advance, where possible. Based on the above, an NSDI can be developed, which includes selecting the coordinate system and MMU, purchasing or allocating GIS hard and software, prioritising accounts to be developed, capacity building, developing data sharing protocols, and developing methods and protocols for spatial analyses. Subsequently, the NSDI can be populated with data, with the ecosystem extent account compiled as a first priority output.

Figure 3.2: Establishing spatial data infrastructure and spatial units for Ecosystem Accounting



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

3.80. Ideally, in order to facilitate ecosystem accounting, ecosystem extent maps should be sufficiently detailed to indicate the uses of ecosystems, for instance type of perennial crops grown, forests being used for logging or being strictly protected, natural shrubland compared to shrubland resulting from forest degradation. Generally, this requires the integration of different datasets, e.g. on land cover, cadastral information indicating land use, soil maps, hydrological maps, information on the location of protected areas and vegetation maps. An NSDI will prove invaluable for the integration of these data. An example of a relatively comprehensive ecosystem extent map is provided in Box 3.1.

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

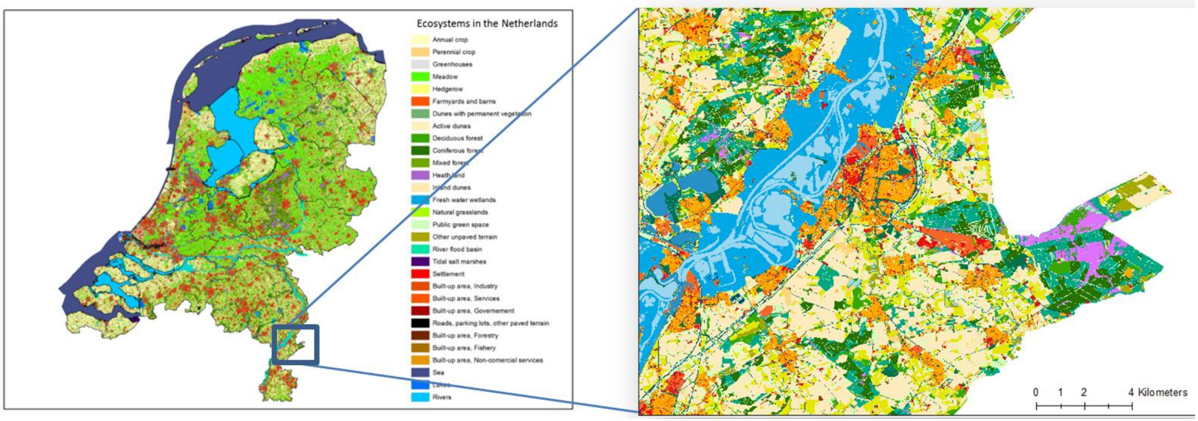
Box 3.1: Development of an ecosystem extent account in the Netherlands

In 2015, Statistics Netherlands, in a project carried out in collaboration with Wageningen University (WUR), developed an ecosystem extent account for the Netherlands. The account comprised a detailed map of ecosystem assets in the Netherlands, plus 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 the MAES and the SEEA EEA ecosystem types. In line with the SEEA EEA, ecosystem use was defined on the basis of the management of the ecosystems as well as on the basis of the services provided by ecosystems. In low-lying, flood-prone the Netherlands, key ecosystem services are water retention and storm protection. Therefore, in addition to the main ecosystem types of the SEEA EEA, dunes and flood plains were distinguished as ecosystem types. Flood plains along rivers are used as water retention areas which are critical for controlling flood risks. The land cover in these flood plains is mostly grassland. This classification is also helpful for the ecosystem services supply and use account, where water retention is linked to flood plains but not to other types of grassland such as pastures. A key was provided that enables reclassifying the ecosystem types to those of both the SEEA EEA and of MAES.

The ecosystem extent map was produced on the basis of a combination of a number of maps and datasets 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 Netherlands. 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 are present in the Netherlands. Natural and semi- natural areas were classified in detail (e.g. wetlands, deciduous forests, heathlands), whereas the same level of detail was applied to intensely managed and paved areas (e.g. different types of perennial crops, non-perennial crops, greenhouses, roads). This high level of detail allows for precise assessments of e.g. land use intensity and temporal changes in land use. The figure below presents the map at national scale, with the 31 ecosystem types at the highest hierarchical level. At the next level (not shown), 80 different types of ecosystem are distinguished including different types of forest and different types of perennial crop. At this 2nd 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.



Source: CBS and WUR, 2015. Ecosystem Accounting Limburg Province, the Netherlands. Part I: Physical supply and condition accounts. To download the full report: http://www.wur.nl/en/Expertise-Services/Chair-groups/Environmental-Sciences/Environmental-Systems-Analysis-Group/Research/Ecosystem-Services-and-Biodiversity/Ecosystem-Accounting.htm

3.7 Key research issues in delineating spatial areas for ecosystem accounting

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

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

3.84. Second, the framework including EA, ET and EAA has been developed in the context of terrestrial areas. At the same time, there have been a range of studies applying ecosystem accounting to coastal and marine areas. These studies include work in South Africa (Driver et al., 2012), Canada (Statistics Canada, 2013), Mauritius (Weber, 2014b), United Kingdom (UK) (UK ONS, 2016) and Australia (Australian Bureau of Statistics, 2015)); and to river and freshwater systems (e.g. South Africa (Driver, et al., 2012), Canada (Statistics Canada, 2013) and Australia (Victorian Department of Sustainability and Environment, 2013). Further, the importance of accounting for marine areas is well recognised and further research is required to fully consider the spatial framework in these contexts.

3.85. Two specific challenges here are (i) to integrate the linear (usually vector-based) datasets generally required for accounting for rivers with the datasets required for terrestrial ecosystems; and (ii) to understand and include in the accounts the interactions between terrestrial systems and river flows (such as the variation in water flows throughout the year (through seasonality and extreme events), exchange of nutrients between river and terrestrial ecosystems, etc.).[21] The second challenge has been captured in a range of hydrological modelling efforts, but this has seldom been done at a scale (e.g. nation-wide) commensurate with scales typically considered in accounting.

3.86. Third, further research is needed to appropriately incorporate some specific ecological areas and aspects. This includes incorporation of information on soil resources and their properties, linear features (such as hedgerows and roads) and subterranean ecosystems (such as caves and groundwater systems). It also includes areas not currently within scope of ecosystem accounting such as the atmosphere and airsheds. With respect to the atmosphere a question is, for instance, whether it could be included in the SEEA EEA as an ecosystem type which would then require delineation vertically rather than horizontally. Interactions between the atmosphere and other ecosystem types can in principle be quantified but there are as yet no examples of this being tested.

3.87. Fourth, the delineation of spatial areas (as well as the compilation of the condition and the physical ecosystem services supply and use accounts) may involve the use of remote sensing data including satellite Earth Observation data. Where there is an agreed national land cover map this should be utilised. Otherwise, there is an increasing availability of such data including freely available data from MODIS (with

[21] Some discussion of these issues is provided in SEEA Water in respect of the measurement of water quality.

medium spatial resolution since 2000, high temporal frequency and including derived products such as land cover, vegetation dynamics and NPP), Landsat (several bands (wavelengths) available at 30m grid since 1984 but with lower temporal frequency) and, recently, Sentinel (including the Sentinel I radar sensor and the Sentinel II optical sensor, with grid sizes of 10m for some bands of the optical sensor).

3.88. For each of these sources of satellite data there is a dedicated website where images can be downloaded. Most images and products from MODIS and Landsat can be accessed from (https://earthexplorer.usgs.gov/). Processing and interpretation of images is required if the available products are not sufficient, as well as dealing with issues such as cloud cover (for optical sensors). Further, there is the related challenge of uncertainty in spatial interpretation and the need for validation and ground truthing of the classified land cover, estimated NPP and other map products. These challenges are not unique to ecosystem accounting but developing methods for adapting remote sensing data for ecosystem accounting purposes is an important area for testing.

4 The ecosystem condition account

Key points in this chapter

"Ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics." (SEEA EEA 2.35). The measurement of ecosystem condition is a central aspect 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 ecosystem characteristics for different ecosystem types. Within this broad framing there are different approaches to the measurement of condition ranging from more aggregated to more detailed.

Generally, the development of indicators relating to characteristics such as 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.

For some characteristics in certain ecosystem types, condition metrics are well established although further testing is required to assess their use for ecosystem accounting. In other cases, the selection and measurement of relevant characteristics is less established and measurement is more difficult.

A key challenge for ecosystem accounting is developing a full coverage of measures in a manner that support aggregation and comparison. In particular, the establishment of composite indicators integrating different condition parameters within different ecosystem types and ecosystem assets poses a core issue.

Reference condition approaches are one technique for developing measures that can be monitored over time and can be compared across ecosystem types and across countries. Determining reference conditions for multiple ecosystem types and more than one country is not straightforward and further testing of relevant approaches for ecosystem accounting is required.

In advancing work on ecosystem condition measurement, it is essential that experts with knowledge of local ecosystems are engaged to ensure the relevance of selected metrics and to take advantage of existing monitoring and research.

4.1 Introduction

4.1 In the SEEA EEA, the general ambition in accounting for ecosystem condition is to bring together the relevant pieces of information to provide an overall assessment of the state or condition of various ecosystems in the ecosystem accounting area. The general definition of ecosystem condition is provided in the SEEA EEA: "*ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics.*" (SEEA EEA, para 2.35).

4.2 The ecosystem condition account captures, in 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 the condition accounts organise aggregated, high-level information and indicators for an ecosystem accounting area, and they typically integrate information from different environmental monitoring systems (e.g. on biodiversity, water quality, soils, etc.). Hence, the ecosystem condition account aims to builds upon and not replace information from various monitoring systems. Compiling a comprehensive condition account will also likely require collecting and analysing additional data (e.g. from remote sensing images) and extrapolating or interpolating existing data.

4.3 The main benefit of compiling an ecosystem condition account lies in the integration of different sets of information of ecosystem condition and in the subsequent potential in the ecosystem accounting framework to combine this information on ecosystem condition with information on ecosystem services flows and monetary value of ecosystem assets. This integrated approach, using as a base a common understanding of the size, composition and types of ecosystem assets, offers a more comprehensive insight into changes in ecosystems compared to individual datasets, thereby expanding the policy use of environmental information.

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, such as to provide values of condition indicators by EA. In the fully spatial approach, accounting tables and maps are produced for all or the majority of indicators so that spatial differences in ecosystem condition of EAs are 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. These indicators may reflect such aspects as the occurrence of species, soil characteristics, water quality, and ecological processes (e.g. net primary production). The indicators selected should be relevant for policy and decision making, for instance because they reflect policy priorities (e.g. preservation of native habitat); pressures on ecosystems (e.g. deposition levels of acidifying compounds versus critical loads for such compounds) or the capacity of ecosystems to generate one or more services (e.g. attractiveness of the ecosystem for tourism). Generally, different ecosystem types require different indicators. For example, condition indicators relevant for forests will be less relevant for cropland.

4.6 Basic spatial or non-spatial information about ecosystems that is commonly needed for the measurement and modelling of ecosystem services supply, are not of the highest priority for a basic condition account. For example, to model erosion risks and the ecosystem service of erosion control, it is necessary to have information on, among other things, rainfall, slope, slope length, and soil type for relevant ecosystem assets. However, these indicators reflect ecosystem characteristics that do not generally change rapidly over time and hence are not key indicators of the changing condition of an ecosystem. Nonetheless, the collation and organisation of this information is likely an important aspect in developing a complete database for ecosystem accounting, and such information can be included in annexes to the ecosystem accounts.

4.7 Discussion since the release of SEEA EEA has highlighted the following points that provide a broader context for the measurement of ecosystem condition.

4.8 First, the relevance of ecosystem condition indicators depends upon context. In part, this reflects that the assessment of condition should take into consideration the specific characteristics of the EAA including the ETs that are present, their composition, and the likely uses of EAs. Data availability, or the possibility to obtain additional data, are additional considerations in selecting condition indicators. Thus, determining the appropriate set of characteristics is a particularly important task for testing in ecosystem accounting. Recent discussion highlights that it should be possible to give additional guidance as to the broad aspects that a set of indicators should cover (e.g. habitat, pressures and drivers, biological responses, see also box 4.1) but this requires further discussion in an accounting context.

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

4.10 Third, in some cases, it may be useful to compile composite indicators where a range of indicators is combined to reflect different elements of ecosystem condition. However, having determined a suitable set of indicators, there is no natural, a priori weighting of the indicators that might be used to estimate the overall condition of an ecosystem asset. Thus, a measure of the overall condition requires a view to be taken on the relative importance of the different ecological processes involved, or the different purposes for use of an ecosystem asset. It would be possible to give each indicator equal weight, but this does not overcome the underlying issue. Alternatively, weights may be determined via surveys of ecosystem users.

4.11 It will often be useful to compare individual or composite condition indicators to benchmark or reference conditions. This approach is discussed at more length later in this chapter. Condition indicators may also be attributed to specific classes on the basis of an assessment against standard criteria. This is sometimes done with classes reflecting different levels of soil fertility or land suitability for a specific purpose.

4.2 Different approaches to the measurement of ecosystem condition

4.12 There are three broad measurement approaches that can be used to compile ecosystem condition accounts. All three approaches are plausible ways forward for the measurement of ecosystem condition. Further, each of these measurement approaches can be implemented in a minimum, partial or fully spatial approach. Testing is required to understand whether there is a significant difference in the results from the use of different approaches, and which approaches might be most appropriate for ecosystem accounting purposes. This issue is discussed further in section 6.5.[22]

4.13 The first approach is an aggregate approach where indicators for a small set of generally applicable ecosystem characteristics across a country, are combined to form an overall condition measure. Forming the overall measures requires the use of assumptions on the relative importance of each characteristic and correlations among them. This is the approach adopted for the ENCA QSP (Weber, 2014a) where indicators 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 approach is a detailed approach in which different characteristics are determined for different ecosystem types. This is the approach that has been used in South Africa (Driver et al., 2012; Nel & Driver, 2015), in the Canadian Measuring Ecosystem Goods and Services (MEGS) project (Statistics Canada, 2013), in the Norwegian Nature Index (Certain, Skarpaas, et al., 2011) and by the Wentworth Group in Australia (Sbrocchi, et al., 2015)[23]. In theory, it may be possible to combine the various indicators of the different characteristics to provide aggregate measures of condition but this step is not generally taken. Perhaps the closest to undertaking this step is in the work of the Wentworth Group through their development of the "econd" as a reference condition based indicator; and in the aggregate indexes of the Norwegian Nature Index. In these approaches, the naturalness of the ecosystem is one of the considerations in defining the reference condition.

[22] See also reflections on the measurement of ecosystem condition within the EU KIP INCA project (La Notte, et al., 2017)

[23] Note that the ENCA QSP approach also supports the use of additional indicators beyond an initial standard set.

4.15 The third approach is a variation on the detailed approach and involves selecting the condition indicators through a direct link to the basket of ecosystem services for a given ecosystem asset and, in doing so, taking into account factors such as proximity to population and land management and use. This is the approach used in the UK natural capital accounts (UK ONS, 2017) and relates to the concept of measuring ecosystem capacity (see section 7.3) where the ability for an ecosystem asset to continue to produce a given ecosystem service is a function of the ecosystem condition. In this approach, condition indictors should be selected that can be used to assess ecosystem capacity (see Chapter 7).

4.16 While all three approaches can be adopted for the measurement of the concept of ecosystem condition as defined in the SEEA EEA, they are each have a slightly different interpretation of condition insofar as condition can be considered to be a strongly ecological concept or one that also takes into account non-ecological factors, such as environmental pressures and indicators relating to ecosystem use. Each interpretation along this continuum will lead to the selection of different characteristics and indicators, recognising that ecological characteristics will be important in all cases. A key area of ongoing research and discussion relates to the appropriate selection of ecosystem characteristics for the measurement of condition for accounting purposes.

4.3 Ecosystem condition accounts

4.17 A central feature of ecosystem accounting is organizing biophysical information on the condition of ecosystem assets within an EAA. An example of an ecosystem condition account in shown in Table 4.1 where the account is compiled in physical terms using a variety of indicators for selected characteristics. The accounting structure provides a basis for organising relevant indicators by ecosystem types and for distinct points in time (opening and closing of the accounting period).

4.18 Table 4.1 provides a basic structure of a condition account. In practice, the indicators in the rows can be defined in five different ways as explained in section 4.4.2. Accordingly, the rows in Table 4.1 may reflect a number of 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, and each of these indicators may be recorded in the table. Alternatively, again by way of example, for the ecosystem type of inland water bodies and the characteristic of water quality, indicators of pH, turbidity and oxygen content levels may be combined for form a single indicator. Note also that although not shown in Table 4.1, the condition account may also include indicators reflecting human pressures and non-ecological factors.

4.19 Generally, these accounts should be compiled by ET (as shown in Table 4.1 using SEEA Central Framework land cover classes as proxies for ET). This is because each ET (e.g. tree-covered areas, grasslands, mangroves, etc.) will have distinct characteristics that should be taken into account in assessing condition. This approach also recognizes that much information on ecosystem condition is available by ecosystem type rather than in reference to broader, landscape-type scales or administrative boundaries. Consequently, harnessing available scientific information and expertise for the measurement of condition may be more readily achieved through a focus on ETs.

Table 4.1: Initial example of an ecosystem condition account

		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 inter-tidal areas	Sea and marine areas
Example indicators of condition		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Vegetation (e.g. native cover)	Opening condition															
	Closing condition															
Water quality (e.g. turbidity, pH)	Opening condition															
	Closing condition															
Soil (e.g. erosion, pH, nutrients)	Opening condition															
	Closing condition															
Carbon (e.g. net primary productivity)	Opening condition															
	Closing condition															
Biodiversity (e.g. species richness)	Opening condition															
	Closing condition															
Habitats (e.g. fragmentation)	Opening condition															
	Closing condition															
Overall index of condition	Opening condition															
	Closing condition															

4.20 The structure of the ecosystem condition account in Table 4.1 is focused on recording information at two points in time, i.e. it presents information on the condition of different 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/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 at higher frequencies (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 annual or bi-annual updates may be sufficient to monitor long-term trends in some cases.

4.21 Underpinning these accounts will be information from a variety of sources. In some cases, source data may itself be organized following accounting approaches. Examples include information concerning land cover, water resources, nutrients, carbon and species-level biodiversity. Accounts about these themes are discussed in Chapter 9. There is no conflict or double counting implied by recording information on the same topic in different accounts. 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 in estimating the supply and use of ecosystem services and changes in the stock of water resources.

4.22 Overall, there is a range of measurement issues and challenges in the compilation of ecosystem condition accounts. Indeed, it is reasonable to conclude that there is still much to learn about the structure and compilation of these accounts. Particular issues concern the selection of characteristics for different ecosystem types, the relevant indicators for different characteristics, the potential to aggregate across different characteristics to derive an overall measure of condition for a single EA, the aggregation of condition measures for ET, recording condition measures that are relevant for combinations of ET (e.g. concerning 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 these issues.

4.4 Developing indicators of individual ecosystem characteristics

4.4.1 Selecting indicators

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

4.24 For a given characteristic, often the research enables the relative importance of the different factors to be weighted to provide an appropriate composite index. The challenge is not whether indicators of specific characteristics of ecosystem condition can be measured, but rather which characteristics are relevant and how the indicators might be combined.

4.25 If a fully spatial approach to ecosystem condition accounting is adopted, then ideally, information on each selected characteristic would be measured or downscaled to the BSU level. In many cases this 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 will be some situations in which downscaling may make little conceptual sense or imply assumptions in downscaling that are not appropriate. For example, in measuring ecosystem condition for the purpose of providing habitats, measures of fragmentation and connectivity are likely to be highly relevant. These characteristics are conceptualised and measureable at a multiple ecosystem asset level. 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 One type of indicator not mentioned in SEEA EEA but which should be given further consideration are functional indicators, for example of ecosystem resilience and integrity. This may include, for instance indicators of physical or biological ecosystem properties that reflect an ecosystem's resilience for extreme events (see Carpenter et al., 2010 for an overview). To the extent that scientific research has established a functional indicator that relates well to the concept of ecosystem resilience, then such indicators may be used directly for particular ecosystem types or may provide an indication of the characteristics that should be the focus of condition measurement.

4.28 For example, even though a large number of indicators for coral reef condition have been used in various monitoring and research programs, the indicator 'percentage live coral reef' is considered a good aggregate indicator for coral reef condition. Even though for site specific coral reef management other types of information may be needed, this indicator may therefore be useful to express overall trends in reef condition for an EA or ET. Where appropriate and where data are available this indicator could be supplemented with a limited number of other condition indicators for instance reflecting the presence or abundance of fish or other species indicative of habitat quality, ecosystem functioning or correlated to ecosystem services (e.g. fisheries or recreation).

4.29 However, generally, 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 scope of ecosystem accounting. Instead, it is more likely that ecosystem condition accounts can provide an organising 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 would require the use of a vast number of characteristics. From an ecosystem accounting perspective, the intention remains to provide a broad indication of the level and change in condition rather than to fully map the functioning of every ecosystem asset. In this regard, a key element of accounting is monitoring change over time and hence a focus on those characteristics that reflect changes in ecosystem condition is an important consideration. Based on assessments of the various projects referred to above, it seems that for most ecosystem types a set of 4-8 indicators can provide a sound/robust set of information to enable assessment of the overall condition of an ecosystem asset.

4.31 Five considerations that should be used in selecting indicators are (i) the degree to which the indicator reflects the overall ecological condition of the ecosystem or key processes within it and is able to signal changes in this condition; (ii) the degree to which the indicator can be linked to measures of potential ecosystem services supply (iii) how easy it is for policy makers and the general public to understand and correctly interpret the indicator; (iv) data availability and scientific validity of measurement approaches for the indicator; and (v) the possibility to generate new data cost effectively. Note also that ecosystem condition will, in general, be more strongly linked to potential ecosystem services supply than to actual ecosystem services supply since the latter depends on the extent of use of the ecosystem by people.

4.32 To demonstrate the potential in this area, Box 4.1 shows tables for indicators of ecosystem condition for different ecosystem types based on research in South Africa.

4.33 In terms of data sources, these will vary depending on the indicator selected. In the areas of monitoring carbon, water and species-level biodiversity, a range of potential data sources is introduced in Chapter 7. The ENCA QSP (Weber, 2014a) also proposes many data sources in these areas. In many cases, satellite based data are likely to be useful information especially in providing the breadth of data across different ecosystem assets that is required for ecosystem accounting purposes.

4.34 Compilers are encouraged to consider the work described in the project research papers, the outcomes from testing in different projects, and most importantly, to engage with national experts on ecosystems and biodiversity measurement noting that there may be different experts for different ecosystem types. A particular ecosystem type to commence testing may be forests 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 may be discussions with experts involved in national reporting on the state and trends in biodiversity with the framework of the Convention on Biological Diversity (CBD). Other international programs on ecosystem monitoring and measurement will also be relevant including for example the collection of information to monitor the UN Sustainable Development Goals and data collected through the GEOSS program (e.g. within the Earth Observation for Ecosystem Accounting (EO4EA) initiative.[24] Within Europe, projects such as MAES, the EU Habitat Directive and Copernicus will provide relevant information. Overall, the ecosystem condition account is likely to be the primary account through which engagement with the ecological community can be fostered.

[24] https://www.earthobservations.org/activity.php?id=111

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 South Africa and applies this to other ecosystem asset classes, for details see Nel & Driver (2015).

Some key points about the proposed approach:

- For each broad class of ecosystem assets (e.g. terrestrial, river, wetland, coastal, marine), four to six *indicators of ecological condition* are measured on a scale of 0 to 1 (or 0 to 100). These are aggregated to give an *overall index of ecological condition*. Some examples are given in the tables that follow 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)
- Ecologists in the different classes (terrestrial, freshwater, marine) have done substantial thinking on how to measure ecosystem condition, and it is important to draw on this existing work in the process of developing the condition accounts for a particular class of assets. It is essential for ecologists to be closely involved in the selection of indicators of ecological condition, and in determining the method used for aggregating them, to ensure that the result is ecologically meaningful and sensible.
- It is not possible to come up with 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. The set of indicators of ecological condition eventually selected for a particular asset class may depend partly on data availability, but ideally should not be driven by data availability as the starting point.
- All indicators should be assessed/quantified in relation to a reference condition for the ecosystem type concerned. Where possible, the reference condition is the natural or near-natural condition in the absence of significant modification by human activity. If this is not possible, an alternative stable reference condition can be selected (e.g. condition at a particular baseline date).

Below are some examples of what the tables might look like for different classes of ecosystem assets. These are simply suggestions to illustrate the approach – the indicators suggested here are not intended to be exhaustive or definitive.

Terrestrial ecosystems

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

River ecosystems

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

4.4.2 Aggregate measures of condition

4.36 Where indicators of individual characteristics are available, the next question for ecosystem accounting concerns if and how aggregation of indicators to obtain overall measures of ecosystem condition for a single ET and for multiple ecosystem assets within an EAA is required. As noted in the introduction to this section, the development of overall measures of the condition of ecosystem assets remains a challenge in measurement terms.

4.37 In considering aggregation, a primary objective in ecosystem accounting is to provide decision makers macro-level information that supports understanding the relative state of different ecosystems. Usually, there will be a limited set of resources available to influence ecosystem condition and hence choices must be made among a range of investment options. Ideally, macro-level information would give a sense of the overall condition of each ecosystem relative to the other (i.e. the comparison of EA and ET in different locations) and also relative to relevant thresholds and limits, recognising the need for specialist ecological knowledge to describe these thresholds and limits.

4.38 However, especially in early phases of ecosystem condition account development, care needs to be taken that uncertainties and limitations are properly communicated to the users of the accounts. It is likely that in the near future the condition accounts will be insufficiently detailed to be able to serve as the sole source of information for decision making, and that site-specific resource management questions need to use the accounts as a starting point for discussion.

4.39 In moving from individual indicators of specific characteristics to information on relative overall condition, a continuum of information can be described. Moving along the continuum reflects the use of additional information and assumptions. In general terms, as the number of ecosystem types increases, it is likely to be more difficult to make comparisons. It needs to be noted that further testing is required before more specific guidance can be given, in particular on points iii to v.

4.40 The continuum is as follows:

i. At the most basic level, there will be information on individual characteristics that can be measured directly. For example, the pH level of soil or the biomass of a forest can both be measured in absolute terms.

Looking at these measures over time can provide information on the ecosystem's condition.

ii. For some characteristics, it may be necessary to compare the chosen metric with a known baseline, standard, threshold or limit, to be able to infer something about ecosystem condition. For example, measures of water or air quality will rely on both direct measures of pollutants and an understanding of how the observed measure compares to a relevant standard.

iii. At the third level, still for a single characteristic, a composite indicator could be formed whereby a number of indicators are weighted together. For such a composite indicator to be meaningful, it is necessary that the component indicators are measured or interpreted in relation to a common baseline or standard. Note that for many characteristics, for specific ecosystem types, measurements at these first three levels are well developed in the literature.

iv. At the fourth level, the aim is to consider, for a specific ET, some combination of indicators, where each indicator relates to a different characteristic. Two issues arise, first the selection of characteristics, and second the means of combination. The first issue has been discussed in the previous section. The solution to the second issue, as proposed in the SEEA EEA, is the use of a reference condition, whereby indicators for each characteristic are compared to the same reference condition for that ecosystem.

v. At the final level, assuming that measures of ecosystem condition can be established for each ET (i.e. at level four), it is necessary to find a means of comparing across different ecosystem types. Again, the use of reference conditions is a possible way forward where, in this case, all ET are compared to a single reference condition. Selecting a reference condition applicable to all ecosystems in a country, however, is a major challenge both from a conceptual and from a data perspective. One potential option is to select a specific year in order to define reference condition, however any selected year will to be arbitrary to some extent. A further extension at this level would be comparisons between countries.

4.41 Given the desire in accounting for macro-level information, it is the challenges in measurement and interpretation at the last two levels that is of particular interest. A focus is thus on the extent to which singular reference conditions can be used to either compare within ETs, and/or to compare across ETs. This is discussed further in section 4.4.3 immediately below.

4.42 Assuming that an appropriate reference condition can be determined, the next step is to normalise each indicator. This is commonly done by setting the reference condition to a "score" of 100 and recording the actual condition as a score between 0 and 100. A related approach is to grade ecosystems on a scale of A – F (or similar), with A representing the reference condition and F representing a condition most distant from the reference.

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

4.44 While the use of reference conditions is well known and practiced, the precise choice of a reference or benchmark condition for accounting purposes requires further discussion and testing. SEEA EEA notes a number of conceptual considerations with respect to the use of reference condition approaches and Bordt (2015a) provides a more complete consideration of different reference condition approaches. A short summary of the issues is provided in the following sub-section.

4.45 Finally, following the logic outlined earlier in this section, even where each indicator can be compared to an agreed reference condition, there remains the second step of weighting together indicators of the different characteristics. The ambition is not new from a statistical perspective (consider for example the Human Development Index (UNDP, 2014)). However, as for socio-economic indicators, the weighting of different ecosystem condition indicators is 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 with different characteristics possibly playing a relatively more important role. Also, equal weighting may not reflect the relative importance of different characteristics in the potential supply of ecosystem services, or take into account various thresholds and non-linearities which may apply in aggregating indicators that relate to different aspects of condition.

4.47 An extended discussion on aggregation of ecosystem measures is provided in Bordt (2015b). That paper points to a number of options and issues. At this stage, no clear pathways forward have emerged but there are a number of areas for testing and research described below in section 4.5.

4.4.3 Determining a reference condition

4.48 As noted above, determining an appropriate reference condition is not straightforward and can be the matter of considerable debate. The discussion here provides a short summary of the key points from an ecosystem accounting perspective.

4.49 A common starting point for determining a reference condition is application of the idea of close-to natural or pristine condition where the reference condition reflects the condition of the ecosystem asset if it had been relatively unaffected by human activity. In many cases the application of this reference condition is done by selecting a point in time at a pre-industrial stage. In Australia, for example, the year 1750 is commonly used.

4.50 A positive feature of this approach is that it places all ecosystem assets on a common footing and "distance from natural" can be interpreted relatively equivalently irrespective of the type of ecosystem. That is, it is possible to compare ecosystems that are either extremely diverse, such as rainforests, or much less diverse such as deserts.

4.51 Unfortunately, what constitutes a natural ecosystem can lead to significant debate particularly in those countries where human influence on the landscape has been evident for thousands of years. For example, almost all of Europe may be considered to have been forested at one point in time, but the use of this as a reference condition for the current mix of ecosystem types is likely inappropriate because most of Europe's landscapes have been modified by people for several thousands of years. Many of Europe's fauna and flora species have had time to adjust to the management of these landscapes by people and would not necessarily benefit from conversion to full forest cover. In addition, the specific composition of the forest under natural conditions has changed considerably in the last millennia and the choice of the specific forest to represent natural conditions would always be arbitrary.

4.52 Another concern about the use of natural reference conditions for ecosystem accounting is that they will 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 then assessment of condition in terms of “distance from natural” will not compare like with like. This links directly to the earlier discussion on the use of ecological and non-ecological factors in the assessment of condition. As this discussion progresses the link to defining an appropriate reference condition must also be made.

4.53 A related concern that arises is that the reference condition can be mistakenly interpreted as a target or optimal condition. A clear distinction should be made between reference and target conditions. A reference condition should be used solely as a means of estimating relative condition and comparing across ecosystem characteristics and ecosystem types. Target conditions, on the other hand, should be developed through participatory processes, taking into account economic, social and environmental considerations. For example, in urban areas the actual condition would be likely very low or zero relative to a reference condition of the previous natural state of that area. Hence, it would be inappropriate to suggest that the target condition should be the natural state. A more appropriate target condition in urban areas might be the planting of additional trees to contribute to improved air quality. Generally, it would be expected that information on the actual and reference condition presented in ecosystem accounts would be useful input to a discussion of 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 on this approach is to select the condition at the point in time at which the accounts commence.

4.55 The difficulty with this approach is that ecosystems that may have been heavily degraded in the past will be compared from the same starting point as those that have not been degraded at all – i.e. both would be given a reference condition of 100 at the selected point in time.

4.56 On balance then, some degree of discretion is required in the selection of a reference condition as well as transparency in methods and assumptions. In making a decision, an important consideration is the scale of analysis. In general, it will be more challenging to determine a reference condition as the scale of analysis gets larger since there are more factors to take into account. Thus, if the intent is to only measure the condition of a specific characteristic (e.g. soil condition) of a specific ecosystem type (e.g. open grasslands), then the choice of reference condition may be made taking only that characteristic and ecosystem type into account.

4.57 However, where there is a desire to compare multiple characteristics and multiple ecosystems, then a relevant single reference condition will not be readily apparent. For some countries, it may be that a pre-industrial time point gives an appropriate reference condition, since there is a point in the not too distant past where a relative common understanding of change from a reference condition can be understood. As noted though, such a choice will likely not be appropriate where the current landscape mix of ecosystem types has, to varying degrees, been evident for centuries and a pre-industrial reference condition will only reflect ecological characteristics.

4.58 Assuming a national level reference condition can be determined, a remaining challenge is to find a reference condition that allows comparison across countries. Given the diversity of landscape development patterns this choice is not at all obvious.

4.59 Pending further testing of different approaches to defining reference conditions, it is recommended that 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 allow the development of the relevant metrics of current condition and the application of the reference condition approach. This is a pragmatic starting point, particularly for the measurement of change over time within a country and can support a focus on the direction and strength of trends in condition. It should also help focus discussion on the challenging measurement issue of actually selecting the indicators and maintaining ongoing time series. Using a relatively distant reference point, rather than the beginning of the accounting period, will better support the assessment of distance from thresholds for ecosystem assets.

4.60 To allow for comparison across countries, it will be necessary to move towards common structures for the organisation and presentation of data on ecosystem condition. Testing options for common structures that are both meaningful for comparison purposes and also feasible for implementation is important. Another point for testing is the potential for a country to use one reference condition domestically, but to use a different reference condition for international comparison.

4.5 Recommendations for compiling ecosystem condition accounts

4.61 The measurement of ecosystem condition following the concepts in the ecosystem accounting model is a complex task due the need to consider multiple ecosystems and multiple characteristics. At the same time, there is sufficient research in the general area of condition measurement to suggest that the testing of different approaches in ecosystem accounting projects is quite possible and should 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 instance, soil nutrient concentration may be highly relevant as an indicator of soil fertility and thereby ecosystem condition, and have important repercussions for potential ecosystem services supply, but aggregating this indicator is difficult. The average soil nutrient concentration is meaningless since this may theoretically include 50% of the area with very little soil nutrients and 50% of the area with excess nutrients. Therefore, classifications (e.g. of soil fertility class) or comparison with reference conditions (e.g. deviation from not degraded nutrient content) may be required.

4.63 Approaches to aggregate over space, over time and over ecosystem types will depend upon policy questions, data availability and the required accuracy of the condition account. It is recommended that the account be developed step-wise, by first setting up the account for specific ETs and using a selected set of indicators. Over time the accounts can be broadened in scope and filled with a larger range of indicators.

4.64 Some general recommendations and steps for the measurement of condition are listed below. In each of these steps, the indicator's scientific validity, the ease of communication and the availability of data should be considered.

- Select the measurement approach, i.e. using a minimum, partial or fully spatial approach, and select a specific ET for initial focus.
- Select condition indicators that represent the main ecological characteristics of the ETs. These may cover characteristics such as vegetation, water, soil, biomass, habitat and biodiversity. Where relevant, condition indicators related to land, water and forests should be compiled following the accounting of the SEEA Central Framework. (This links to the broader role of thematic accounts as discussed in Chapter 9).
- Consider whether indicators reflecting ecosystem integrity could be included (including for example indicators of fragmentation, resilience, naturalness, and ecosystem diversity).

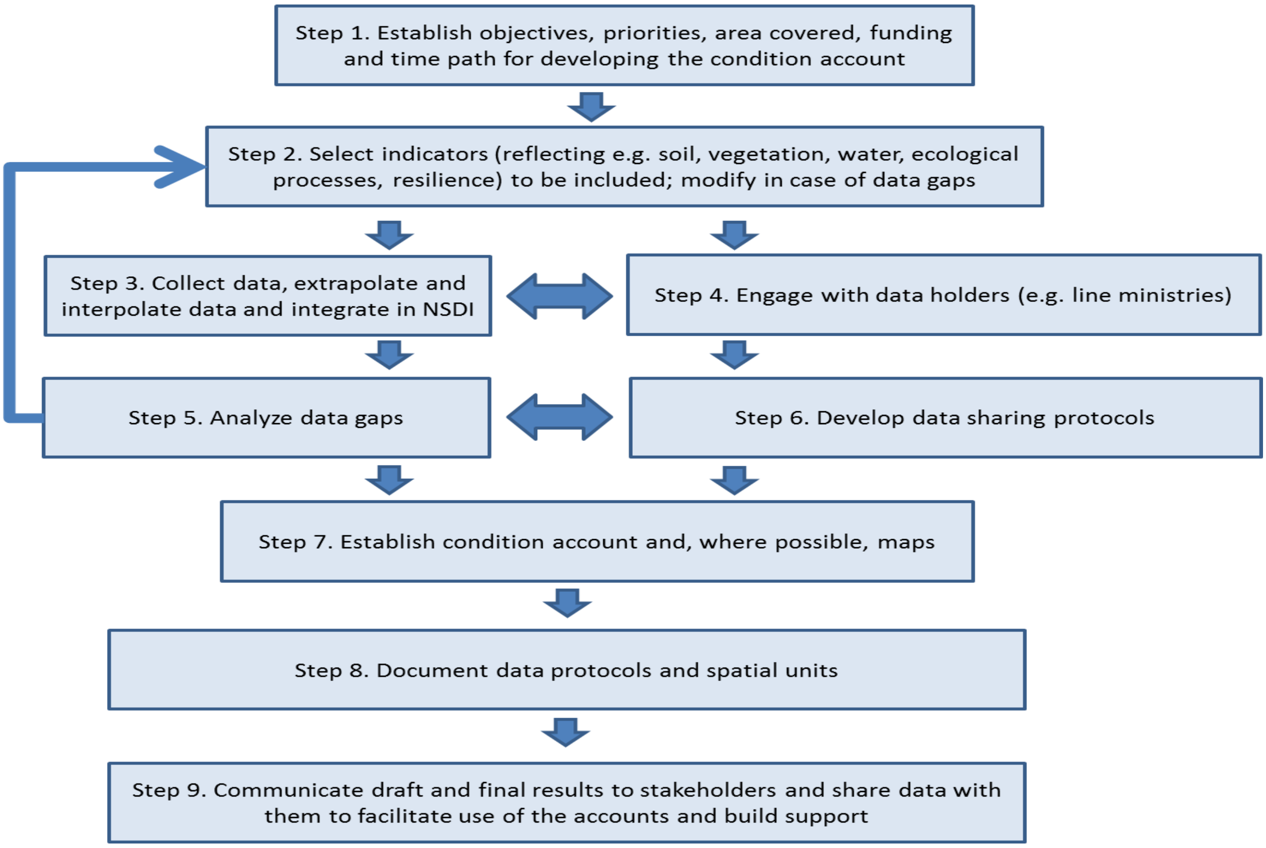
- Consider whether indicators of pressures on ecosystems (or drivers for ecosystem change) should be included in the condition account to support a connection to the supply of ecosystem services.
- Choose an appropriate reference period for the condition measure, or alternatively use the 'opening stock'
- Record and report on the variability and sources of error in the data.
- Once steps are completed for an initial ET, repeat steps for other ETs and then consider whether and how aggregation of indicators across ETs or across the overall EAA is feasible and if so compile aggregate indicators.

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

4.66 Through the development of condition indicators for different ETs it will be important to maintain a good record of the data gaps to provide a basis for engagement with the research community and to prioritise investments in data.

4.67 On the whole, these recommendations are ones that can be tested in applications at country and regional level. A flow chart for developing the ecosystem condition account is provided in Figure 4.1.

Figure 4.1: Compiling the ecosystem condition account



4.6 Issues for research on ecosystem condition

4.68 At this stage in 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. In undertaking this testing there are, however, some specific research questions that should be considered.

4.69 Most importantly, a clearer direction is needed on the extent to which the characteristics used for the measurement of condition go beyond ecological characteristics and also incorporate non-ecological characteristics, including for example indicators of environmental pressures on ecosystems. This issue must be considered so as to provide clarity on the way in which the concept of ecosystem condition for ecosystem accounting purposes relates to the measurement of ecosystem services and concepts of ecosystem capacity and ecosystem capability (as described in Chapter 7).

4.70 Given these requirements for conceptual clarity, specific work is required to identify condition indicators that facilitate connecting condition to the ecosystems' potential and capacity to supply ecosystem services. This includes coming to a better understanding of information gaps, i.e. between the data required to comprehensively monitor ecosystem condition vis-a-vis naturalness and capacity and potential to supply ecosystem services, and the data actually available from the various sources.

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

4.72 Beyond a focus on measurement of condition for specific ET, there also remains work to be done on defining and incorporating condition indicators applicable at larger scales such as habitat fragmentation or ecosystem diversity. This work should also be seen in a broader context of taking into account scale effects in the measurement of ecosystem condition and ecosystem services.

4.73 A final area research is the development of overall indexes of condition for ecosystem assets either based on aggregation of indicators for selected characteristics or using some alternative approach, for example isolating a key characteristic in ecological terms. A range of different approaches are available for aggregation, ranging from using an equal weight for all indicators, to weighing based on expert judgement, or weighing based on specific criteria, for instance in relation to indicators aggregated by ecosystem compartment (soils, vegetation, etc.), by species group (e.g. weighting of insects, mammals, plants, etc.) and/or taking into consideration key ecosystem services.

5 Accounting for flows of ecosystem services

Key points in this chapter

In ecosystem accounting, ecosystem services are defined from the perspective of contributions that ecosystems make to benefits used in economic and other human activity. It is therefore important to distinguish clearly between ecosystem services and benefits.

Generally, most focus for national level accounting is on final ecosystem services. All final ecosystem services have a direct link between ecosystems and economic units.

Intermediate ecosystem services are important for understanding relationships and dependencies between ecosystem assets. They can be incorporated into the ecosystem accounting model but they are not a priority area for measurement. Further discussion and research on accounting for intermediate ecosystem services is required.

The use of a classification of ecosystem services, such as CICES, FEGS-CS or NESCS is an important aspect in compiling estimates of ecosystem services flows.

There are two principal ways to populate the Ecosystem Services Supply and Use account with data. The first approach starts with data that is already in the national accounts and identifies the ecosystem contribution to the benefit involved. Preparation of maps subsequently requires spatial allocation of data on ecosystem services.

The second approach 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. In this case spatial models or direct measures are required to quantify the ecosystem services.

In order to construct the Ecosystem Services Supply and Use account it is necessary to consider the use of ecosystem services by different economic units including households, businesses and governments.

In some cases, biodiversity may be considered a cultural ecosystem service but generally, biodiversity is best considered as a characteristic of ecosystem assets that can be degraded or improved over time, and which 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 glue that enables the connection to be made between ecosystem assets on the one hand and economic production and consumption on the other. Their measurement is thus central to the aim of integrating environmental information fully into the existing national accounts.

5.2. Since the release of the Millennium Ecosystem Assessment (MA) in 2005 (MA, 2005) there has been a strong increase in the number of studies on ecosystem services. The studies have focused on many aspects of definition and measurement, and have involved researchers from a range of disciplines. Subsequent work in the context of the TEEB (The Economics of Ecosystems and Biodiversity) Study (TEEB, 2010a&b), the MAES initiative (Maes, et al., 2014) and the Inter-governmental Platform on Biodiversity and Ecosystem Services (IPBES) have reinforced the potential of the ecosystem services approach in understanding the relationship between humans and the environment. Ecosystem accounting has built upon this work and research. The SEEA EEA attempts to chart a course through the various discussions on ecosystem services and it makes a range of choices about the definition and measurement of ecosystem services for accounting purposes.

5.3. To support discussion in this chapter, the following paragraphs provide a brief summary of the framing for ecosystem services in the SEEA EEA as presented in Chapter 2. In ecosystem accounting, each ecosystem asset generates a set or basket of final ecosystem services which are defined as contributions to the production of benefits. Final ecosystem services encompass a wide range of services provided to economic units (businesses, governments and households) and may be grouped into provisioning services (i.e. those relating to the supply of food, fibre, fuel and water); regulating services (i.e. those relating to actions of filtration, purification, regulation and maintenance of air, water, soil, habitat and climate) and cultural services (i.e. those relating to the activities of individuals in, or associated with, nature).

5.4. Benefits may be either *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, 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 non-SNA benefit. Further, in each sequence of use of ecosystem services and production of benefits there is an associated user or beneficiary being 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 this framing of ecosystem services in ecosystem accounting, this chapter summarises the main points from the SEEA EEA concerning ecosystem services, discusses refinements to the SEEA EEA discussion, and describes the main measurement issues and remaining challenges. Section 5.2 describes the ecosystem service supply and use accounts and section 5.3 discusses issues in the definition of ecosystem services. Section 5.4 considers approaches to the classification of ecosystem services. Sections 5.5 and 5.6 summarize the role and use of biophysical modelling and the relevant data sources, materials and methods for measuring ecosystem service flows. Practical recommendations for compiling an ecosystem services supply and use table are provided in section 5.7, including a flow chart and an example. Section 5.8 presents selected topics for research.

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 generally, and the ecosystem supply and use account in particular, focus on ecosystem services and the connections to the production and consumption of other goods and services. The scope does not extend to measuring the broader costs and benefits that may arise from increased or reduced consumption such as health and social outcomes. Thus, ecosystem accounting does not provide an economic or social welfare perspective on the relationship between people and the environment. At the same time, information on the supply and use of ecosystem services recorded in the accounts will support discussion of relevant welfare outcomes (see further discussion in Chapter 6).

5.8. For accounting purposes, the concept of the supply of ecosystem services is that supply is equal to the use or receipt of the services during an accounting period. That is, supply is **not** recorded if there is no corresponding use. It may be quite relevant to measure the potential or sustainable level of supply that could be delivered by an ecosystem asset (the corresponding concepts of ecosystem capacity and potential supply are further discussed in section 7.3). However, they are not the focus of measurement in the supply and use accounts.

5.9. Recording supply as equal to use reflects 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 (businesses, households, governments) on the other. It is implicitly assumed that each transaction is distinct and hence each ecosystem service is separable.

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

5.2.2 Overall structure of the supply and use accounts

5.11. The structure of the ecosystem services supply and use account is shown in Table 5.1. The various quadrants, labelled A – H reflect the following information. Note that the listing of ecosystem service types in the table is indicative only and, in due course, should reflect an agreed classification of ecosystem services.

- A: No data are recorded in this quadrant as in concept economic units cannot supply ecosystem services.
- B: In this quadrant, the supply of ecosystem services by ET is recorded.
- C: This quadrant is the equivalent of the standard physical supply and use table showing the supply of products by different economic units. This reflects the production of benefits to which the ecosystem services contribute. The scope of products is all goods and services produced in an economy. The economic units are broken down here by type of activity and hence encompass both private and public sector production.
- D: No data are recorded here as, in concept, ecosystems cannot supply products (i.e. goods and services within the SNA production boundary).
- E: Here the use of ecosystem services by type of economic unit is recorded. This includes both the use of ecosystem services as input to further production and the use of ecosystem services as final consumption.
- F: This quadrant provides an opportunity to record intermediate ecosystem services, i.e. services supplied by EAs and used by other EAs. If these flows were to be recorded then the supply of ecosystem services in quadrant B would need to have an equivalently larger scope. (Further discussion on intermediate services is in section 5.3.)
- G: This quadrant is the equivalent of the standard physical supply and use table showing the use of products by different economic units.
- H: No data are recorded here as, in concept, ETs cannot use products.

5.12. The structure of the ecosystem services supply and use account incorporates flows of products. This supports the joint presentation of data on both the ecosystem services used by economic units, and the products (SNA benefits) to which those ecosystem services contribute. In terms of the quadrants of Table 5.1, the output of products such as livestock are 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.) As desired, quadrant G could be used to record inputs of products such as fertilizer or veterinary costs. In effect, each column pertaining to a type of economic unit can be used to record key elements of a production function that includes ecosystem services as inputs.

Table 5.1: Interim ecosystem services supply and use account and product flows (physical units)*

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	Governmens	Households	Accumulation	Rest of the world - 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 inter-tidal areas	Sea and marine areas	TOTAL SUPPLY
										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Ecosystem services																									
Provisioning services																									
Biomass accumulation																									
- Timber																									
- Crops																									
- Grass / fodder																									
- Fish																									
Water abstraction																									
Regulating services					A												B								
Carbon sequestration																									
Water regulation																									
Water purification																									
Air filtration																									
Nutrient/waste remediation																									
Pest & disease control																									
Soil retention																									
Cultural services																									
Enabling tourism and recreation																									
Enabling nature based education and research																									
Enabling nature based religious and spiritual experiences																									
Products					C												D								

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	Governmens	Households	Accumulation	Rest of the world - 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 inter-tidal areas	Sea and marine areas	TOTAL USE
										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Ecosystem services (detail correpsonding to supply table)																									
Provisioning services																									
Regulating services					E												F								
Cultural services																									
Products					G												H								

* The types of ecosystem services shown are indicative only.

5.2.3 Connections to the SEEA Central Framework

5.13. The basic structure of the account comes from the design of physical supply and use tables (PSUT) in the SEEA Central Framework. There are three principle alterations. First, rather than showing just one column representing the environment, there are multiple columns each representing an ET.

5.14. Second, in the SEEA Central Framework PSUT there are three types of flows – natural inputs, products and residuals. In concept, ecosystem services align generally to the concept of natural inputs but in the SEEA Central Framework the coverage is limited to provisioning services and there may be differences in the descriptions of the flows to be considered. Regulating and cultural services are excluded. It is noted that some regulating services are related to flows of residuals (e.g. emissions, pollution, waste) recorded in the SEEA Central Framework, for example, there will be a connection between residual flows of air pollutants and air filtration services. Conceptually, however these are different flows (see further discussion below).

5.15. Third, the ecosystem services supply and use account includes the potential to record intermediate services. Since the SEEA Central Framework does not consider the ways in which different environmental assets may be connected, i.e. it provides an individual resource perspective, the recording of intermediate ecosystem services reflecting the dependencies between ecosystem assets, is a unique feature of ecosystem accounting.

5.16. In line with the SEEA Central Framework, ecosystem services are recorded before deducting any natural resource residuals.[25] Thus, for instance, in the case of timber harvesting, the biomass that is felled reflects the quantity of the ecosystem service in the same way as this is regarded as the flow of natural inputs in the SEEA Central Framework. However, further work is needed on how to define and record flows of natural resource residuals in an ecosystem accounting context.

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 2, 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, in these instances, the farmer and 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, fertiliser, etc.).

5.18. Although in the table the supply of ecosystem services is shown as only emerging from ecosystem assets (quadrant B), there may be interest in attributing the supply of 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 rows and column structures used for quadrant A in Table 5.1. This recording should be reasonably straightforward for provisioning services. However, it may be more difficult to attribute the supply of some of regulating and cultural services to specific economic units.

5.19. Economic units, ecosystem services and residual flows: As noted above, the SEEA Central Framework records flows of residuals (e.g. emissions, pollution, waste). Residual flows are not ecosystem service flows but rather reflect physical flows from

[25] Note these residual flows are additional to the residuals relating to emissions and the like mentioned above.

economic units into the environment. While these are conceptually different flows, there are important relationships to consider. Specifically, several regulating services involve the break-down or absorption of the substances present in residual flows. In this context, these ecosystem services may be considered to provide "sink services", i.e. the ecosystem acts as a sink or receiver of residuals from economic activity.

5.20. From an accounting perspective, the extent of the ecosystem services is limited in two ways. First, there must be a related demand for the service, i.e. there must be a human use benefiting from the break-down or absorption of the residual substances. For example, when rivers purify water from excess nutrients discharged by various economic sectors, a service is only supplied if there is water abstraction for human use downstream where the removal of nutrients provides a benefit (e.g. because of reduced efforts required to clean the water through water treatment). Second, it may be the case that not all of the quantity of residual flow is able to be broken-down or absorbed in ecosystem processes. In this case, the level of the ecosystem service is limited to the quantity of the substance that is absorbed and some quantity will remain unmediated. These excess quantities may be of particular interest in the measurement of environmental pressures as they relate to changes in ecosystem condition. Overall, information concerning residuals is related to but different from ecosystem services and hence entries for residual flows and ecosystem services should not be recorded in a single table.

5.2.5 Compiling the ecosystem services supply table

5.21. A likely challenge in compiling the supply table will be attributing the supply of ecosystem services to a specific EA and ET. This is unlikely to be an issue for provisioning services, but it may be of concern for regulating services and some cultural services in cases where the service is provided through a combination of different EA within a landscape.

5.22. Given this, it is 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 ET for their country or target ecosystem accounting area.[26] In undertaking this task, a classification of ecosystem services (such as CICES, FEGS-CS or NESCS see section 5.4) can be used as a form of checklist.

5.23. It is to be expected that for some 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 service will be supplied as a result of the combined production of neighbouring ET.[27] For example, cultural services supplied by a mix of ETs (e.g. lakes and wetlands). In these cases, some allocation of ecosystem service flow between ET will be required.

5.24. It will be relevant to use this initial table as a discussion document to obtain input from various experts, including specialists in specific ecosystem types and/or specific ecosystem services. It is also important that the development of such a table is informed by people experienced in considering the link between ecosystems and economic and human activity. This should ensure that commonly overlooked services, particular various regulating services, are not ignored. This initial table would also serve as a basis for scoping and prioritising the required work, and comparing compilation exercises across countries (for example comparing lists of ecosystem services attributed to grasslands).

[26] To provide a starting point for this work consider the material in Bordt (2017).
[27] Note that this is different from the notion of combined production where ecosystem services are combined with human inputs (labour, energy, etc.) to produce benefits.

5.25. The proposed ecosystem services supply table (Table 5.1) has columns reflecting the various ecosystem types and rows reflecting different ecosystem services, in this case classified following CICES. In this table, there is no direct recording of the users of ecosystem services, this takes place in the ecosystem services use table. However, it will be important to compile information on the combination of ET, ecosystem services and users at the same time.[28]

5.26. The choice of indicators for measuring the flows of different ecosystem services is discussed in section 5.6 along with relevant data sources and examples.

5.27. The ecosystem services supply table shown in Table 5.1 can be compiled in physical terms and in monetary terms. When compiled in physical terms each ecosystem service will have a different measurement unit. One consequence of this is that there can be no aggregation of different ecosystem services because the relative importance of individual ecosystem services cannot be immediately determined. Aggregation within a single row to estimate a total flow 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 ET and potentially to individual EA.

5.28. Compilation in monetary terms usually occurs by estimating values corresponding to the physical flows of each ecosystem service, noting that direct measurement of values may be possible for some provisioning services. The ecosystem services supply table shown in Table 5.1 can then be extended with additional rows to record the total flows of ecosystem services in monetary terms. The estimation of values for ecosystem services is discussed in Chapter 6.

5.2.6 Compiling the ecosystem services use table

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

5.30. The focus on users arises because, while the supply of ecosystem services can be directly linked to a spatial area (e.g. to an EA), there is no requirement that the location of the user is the same as the location of the area from which the ecosystem service is supplied. This is especially the case 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 et al., 2016). In framing the measurement in this area, it will 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 will be located within the supplying EA, i.e. at the point of extraction or use (e.g. farmers, foresters, fishermen, water supply companies). This will also be true of many cultural services where there is a recreational or touristic component. That is, although the beneficiary will likely reside away from 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, the users will be located in

[28] Note that the FEGS-CS and NESCS structures explicitly incorporate this connection between supply and beneficiaries.

neighbouring ecosystems (for example, air filtration) or will be global users (for example, with respect to carbon sequestration).

5.32. Given the lack of a singular spatial connection, the choice of structure of the ecosystem services use table must be guided by possible uses and analysis of data. The choice made in Table 5.1, is to structure the ecosystem services use table showing the allocation of the total supply of each ecosystem service to the various economic units, without distinguishing the precise location of the user. This allocation provides a framing aligned to the structure of national accounts datasets.

5.33. As for the ecosystem services supply table, the use table may be compiled in both physical and monetary terms. In physical terms, entries will be 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 account 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 6.

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

5.3 Issues in the definition of ecosystem services

5.3.1 Introduction

5.36. Because of the ambition to integrate measures of ecosystem services with the standard national accounts, the measurement scope and definition of ecosystem services in the SEEA EEA is defined 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. For ecosystem accounting, the production boundary is expanded relative to the SNA reflecting 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 much economic production (for example in agriculture, forestry and fisheries) utilizes inputs directly taken from ecosystems but these inputs (and any associated costs of capital) are not recorded in the standard accounting framework. In these situations, the logic of the SEEA EEA is that flows of ecosystem services should be clearly differentiated from the goods and services that are produced. Thus, the ecosystem services represent the contribution of ecosystem assets to the production of those goods and services. In effect, this sets up an extended input-output or supply chain that includes ecosystem assets as suppliers.

5.38. It is noted that the SNA production boundary currently includes goods and services produced through illegal activity and subsistence production, i.e. these products form a part of the set of SNA benefits. The expansion in scope of the production boundary in the SEEA EEA will mean that ecosystem services that provide input to the production of these goods and services will also be recorded. Data and methods for measurement in these areas are discussed in Handbook on measurement of the non-observed economy (OECD et al., 2002).

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

5.40. While this provides a clear rationale the remainder of this section discusses factors that need to be taken into consideration to ensure a clear measurement boundary is established.

5.3.2 Distinguishing ecosystem services and benefits

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

- it allows 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. due to changes in the methods of production)
- it helps in identifying the appropriate target of valuation since the final ecosystem services that contribute to marketed products (e.g. crops, timber, fish, tourism services) will only represent a portion of the overall value of the corresponding benefits.

5.42. For these reasons, the principle of distinguishing between final ecosystem services and benefits is appropriate for ecosystem accounting. It is also consistent with the approach taken in TEEB (2010a), Banzhaf and Boyd (2012) and the UK NEA (2011), although the precise boundaries, definitions and terms applied for distinguishing between final ecosystem services and benefits vary in the different cases.

5.43. In practice, particularly at large scales, the explanation and application of this distinction can be challenging. The issues arise differently for provisioning services, regulating services and cultural services. For provisioning services, the main challenge is effectively describing the various ecosystem services involved in supplying cultivated biological resources[29]. These 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 will vary by production process (e.g. between hydroponic, irrigated and rainfed agriculture), it means that using a measure of output from production as a measure of the quantity of ecosystem service will be 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. in establishing vegetation as part of a carbon capture program). However, note that the description of the service and the benefit will be different. Thus, the description of the service will reflect the action of the ecosystem asset – sequestering carbon or capturing

[29] Cultivated biological resources is a term from the SNA that supports the distinction between biological resources (e.g. timber, fish, animals, etc.) the growth of which is considered the output of a process of production – i.e. cultivated; and those whose growth is the result of natural processes – i.e. natural biological resources.

air-borne pollutants, while the benefits should be described in terms of increased stability of climate and cleaner air. Making this distinction is important to ensure the correct focus for measurement and valuation. Changes in the volume of cleaner air, for example, may be caused by the presence of air filtration services or from reductions in vehicle emissions. Only the former should be the focus of measurement for ecosystem accounting. Note that although there may be costs incurred in establishing or maintaining an ecosystem to support the supply of regulating services, these are not considered direct inputs to the generation of ecosystem services.

5.45. For cultural services, the contribution of ecosystems is relatively passive in that it is commonly the ecosystem providing opportunities for people to engage in activities, learning experiences and the like. Costs may be incurred to facilitate people benefiting from these services, such as the construction of cycling or hiking paths, visitor facilities, etc. Often, cultural services are conceptualised in terms of the benefits that people receive from the engagement with ecosystems. The challenge for ecosystem accounting is to estimate the contribution of the ecosystem itself to the generation of benefits.

5.46. The challenge is to appropriately describe the ecosystem service such that the focus of measurement is appropriate. The focus in describing the ecosystem service should be a description of ecosystem processes that reflect the contribution of the ecosystem to the production of the benefit – i.e. what is the ecosystem doing? Overall, much further discussion on the framing and descriptions of ecosystem services and corresponding benefits will be required to ensure a common understanding of measurement in this area.

5.47. Note that in some cases these challenges are larger where it concerns the physical measurement of ecosystem services, compared to the 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 is comprised of the various ecological processes that underpin the accumulation of wood, such as storing and releasing nitrogen and phosphorus to the trees. In physical terms these services are difficult to quantify and aggregate, and in practice the accumulation of timber (in m3) may need to be taken as 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 a resource rent) in order to specify the value of the contribution of natural capital involved in producing the benefit (see for further detail section 5.4).

5.3.3 Distinguishing final and intermediate ecosystem services

5.48. All ecosystem services, final and intermediate, should be considered in relation to ecosystem processes and ecosystem characteristics within ecosystem assets. A focus only on final services serves to recognise the important role that these processes and characteristics play in directly supporting economic and human activity. Recognising that intermediate services can also be recorded in the accounting framework supports a better conceptualisation of the connections and dependencies between ecosystem assets. This illustrates the potential of ecosystem accounting to recognise the contributions of all ecosystems and associated ecosystem processes wherever they are located and to understand the potential impacts of economic production and consumption on ecosystem assets.

5.49. While it is relatively straightforward using accounting principles to distinguish between final and intermediate ecosystem services, the complexity of ecosystems means that it can be difficult to make this distinction in practice. At an aggregate level, a focus on only final ecosystem services may be sufficient since many intermediate services will reflect services supplied to other ecosystem assets within the same EAA. However, this may not be appropriate when considering the contribution of individual ecosystems or when undertaking accounting for smaller areas or individual ETs. In these cases, it may be quite relevant to understand the contribution of discrete EAs or ETs especially if an important function of an ecosystem asset is to support neighbouring ecosystem assets.

5.50. A typical example would be the intermediate services provided by upstream forests in regulating water flows and limiting sediment content in water that is subsequently abstracted downstream (at which point final ecosystem services would be recorded). In this 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 example concerns pollination. Pollination in croplands may depend upon pollinators that require shrublands or forest habitat, for instance for shelter. If the shrublands or forests would be converted, the pollination service to the croplands would be diminished or lost. In this case, adding pollination services and the biomass accumulation of crops would lead to double counting. Thus, it will be relevant to map and record such intermediate services because otherwise the services provided by different ecosystem types such as forests and shrublands may be underestimated, for instance in spatial planning.

5.52. The use of the term intermediate services may cause some confusion. The following points are relevant in the use of this term in the Technical Recommendations.

i. The use of the term intermediate in this context is analogous to the use of the term in the SNA with respect to flows of goods and services between producing economic units, i.e. intermediate consumption. In ecosystem accounting, intermediate services are supplied by one EA to another EA.

ii. In some circumstances, there may be interest to record flows of services that are internal to an ecosystem asset (just as there may be with flows within an economic unit). These can be recorded as required for analytical purposes but from a supply and use perspective the net position will be zero for a single ecosystem asset.

iii. When considered from an integrated economic-ecosystem perspective, final ecosystem services could be considered to be intermediate to the extent that the ecosystem services are inputs to SNA benefits (currently recorded goods and services). However, the term final ecosystem services is retained due to its common usage and to reflect that these services are final with respect to an ecosystem-only perspective.

iv. In the SEEA EEA, intermediate services were aligned with physical flows between and within ecosystem assets – i.e. inter- and intra- ecosystem flows. These physical flows can be recorded (e.g. of water, nutrients, pollen) and they may be important for some analytical and policy needs. Information on these flows may also be relevant in the estimation of intermediate services but they are conceptually different 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, evidenced by the lack of a physical flow of sediment.

5.53. Notwithstanding the accounting possibilities with respect to intermediate services and that recording these flows may help in better understanding 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 would suggest there are very significant measurement challenges. If information about intermediate services is required, a focus may be placed on measuring or modelling specific production functions (e.g. related to pollination) or using relevant contextual information. Overall, accounting for intermediate ecosystem services is an area for further research and testing.

5.54. Special note is required concerning the treatment of carbon sequestration and carbon storage. In the ecosystem accounting approach, carbon sequestration is considered a final ecosystem service. Carbon sequestration is one of the main ways through which ecosystems mitigate climate change. Hence, the corresponding benefit is reducing the impacts of climate change. Carbon sequestration comprises a flow of carbon from the atmosphere to the ecosystem, based on a variety of ecological processes. In this 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. Only the latter should be considered as providing an ecosystem service.

5.55. Ecosystems may emit carbon dioxide, as well as other gasses such as methane or 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 measurement and valuation.

5.3.4 The treatment of other environmental goods and services

5.56. As noted in the SEEA EEA Table 2.3, not all flows from the bio-physical environment to the economy and society can be considered ecosystem services. There are a range of so-called “abiotic” services reflecting flows received in the form of mineral and energy resources, for instance flows of energy such as solar, wind, wave and geo-thermal energy; and more generally, the space for people to live.

5.57. Since the focus of the SEEA EEA is on accounting for ecosystems, these various flows are not incorporated in the ecosystem accounting model. Many of these flows are accounted for in specific accounts described in the 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 spatially explicit approach outlined in the SEEA EEA may mean that it is relevant to consider incorporating measures of abiotic services to consider the full range of benefits from a defined area. The extension of the accounting tables to consider this aspect has not been developed at this stage and is subject to further development.

5.3.5 The link between biodiversity and ecosystem services

5.58. On the whole, the perspective taken for ecosystem accounting in the SEEA EEA is that biodiversity is a characteristic of ecosystem assets most directly relevant in measurement of the condition of ecosystem assets. This is distinct from an alternative conception that biodiversity is a final ecosystem service supplied by ecosystem assets. Thus, measures of biodiversity, whether of ecosystem-level biodiversity or species-level diversity (the inclusion of genetic-level biodiversity measures has not yet been examined), are considered to relate primarily to the stocks component in the accounting model. This approach is consistent with a view that biodiversity can be degraded or enhanced over time, an attribute that only applies to stocks and not to flows (i.e. ecosystem services). The exact nature of the relationship between biodiversity and ecosystem condition is a matter of some uncertainty. This issue is discussed further in section 9.5.

5.59. At the same time, it is recognised that there are some aspects of biodiversity, especially species diversity, that can supply final ecosystem services. This includes, for example, the value of recreational services from wildlife related activities, where people gain 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 and/or iconic species. In this latter case, specific elements of biodiversity (e.g. related to the conservation of species) could be considered representing a 'final use' of biodiversity. Given these potential links to both ecosystem assets and ecosystem services, it is relevant to recognise that measures related to biodiversity may be appropriate indicators in a variety of accounts.

5.60. Information on biodiversity including on composition, state, functioning, resilience, etc. can be brought together in biodiversity accounts and in ecosystem condition accounts and can be represented in such a way that it can inform biodiversity management. The information in these accounts can include indicators expressing the condition or state of the ecosystem, indicators expressing the ability of biodiversity to support other services such as birdwatching, and indicators representing the appreciation of biodiversity itself such as providing a habitat for endemic species.

5.3.6 The treatment of ecosystem disservices

5.61. Ecosystem disservices arise in cases where the interaction between ecosystems and humans is considered to be "bad". Usually this refers to the effects of things such as pests and diseases that emerge from ecosystems and negatively affect economic production and human life. The SEEA EEA recognises the frequent discussion on the measurement of ecosystem disservices but does not propose a treatment in accounting terms.

5.62. Unfortunately, accounting principles do not work well when trying to record the outcomes associated with the production and consumption of products. Indeed, accounting, as distinct from economics, does not focus on the welfare effects of use, and focuses instead on the activity associated with the generation of products and the associated patterns of consumption. As a consequence, all flows between producers and consumers have positive values in the accounts, irrespective of their possible welfare effects. For example, the production and sale of cigarettes is recorded in the same way as the production and sale of apples.

5.63. A related matter is the treatment in ecosystem accounting of negative externalities, such as emissions, where economic and human activity leads to declines in the condition of ecosystems. Any associated environmental flows, i.e., pollutants, emissions, etc. are not considered ecosystem disservices and their negative impacts on welfare are not captured directly in accounting for ecosystem services. However, the negative impacts are captured in accounting for ecosystem condition and hence, through the accounting system, the effect of negative environmental externalities should emerge over time through reduced flows of ecosystem services, all else remaining constant.

5.64. For both disservices and negative externalities, work is ongoing to outline the appropriate treatment in the context of the ecosystem accounting framework. It is noted that the SEEA Central Framework provides accounting approaches for recording flows of emissions of greenhouse gasses, pollutants and other residuals to support measurement in these areas. Further, stocks and flows related to the measurement of externalities will be recorded in thematic accounts (Chapter 9), particularly in the carbon account. The carbon account records flows (sequestration and emissions) and (changes in) stocks of carbon. Hence this includes recording carbon emissions, for instance from drained peatlands.

5.3.7 The scope of cultural services within an accounting framework

5.65. The discussion and measurement of cultural services in ecosystem accounting is the least advanced area of work. Challenges lie in articulating the distinction between ecosystem services and benefits and in the associated area of valuation. Where businesses are involved in the delivery of tourism and recreational services the treatment is quite clear and parallels the measurement of provisioning services. However, in other cases the framing is less clear. This is particularly the case for so-called "non-use" interactions where people obtain benefits from nature without any direct interaction. It is quite plausible for ecosystem services relating to non-use to be considered within scope of ecosystem accounting. What is far less clear is whether the value of any non-use services would satisfy the valuation principles required for ecosystem accounting. This is discussed further in Chapter 6.

5.4 The classification of ecosystem services

5.4.1 Introduction

5.66. The classification of ecosystem services is an important aspect of measurement since classifications can provide important guidance to ensure that an appropriate breadth and depth of measurement is undertaken or, at least, that individual measures are understood within a broader context. The discussion here focuses on the use of an ecosystem services classification for accounting purposes, but it is recognised that a classification will likely also be utilised in other contexts, i.e., an ecosystem services classification can serve multiple purposes.

5.67. The classification included in the SEEA EEA in System of Environmental-Economic Accounting 2012 was an interim version of CICES. This was updated to Version 4.3 (Haines-Young and Potschin, 2013), and an update to Version 5.0 is planned for 2017.

5.68. CICES has been adopted for work on the European Union's MAES project (Maes, et al., 2014) but alternative approaches to the classification of ecosystem services have also been developed. Over time, it will be necessary to consider the different merits and roles that might be played by the different classifications. Perhaps the most important alternative approaches are the work by the United States Environmental Protection Agency (US EPA) on a classification system for final ecosystem goods and services (FEGS-CS) (Landers and Nahlik, 2013) and the associated National Ecosystem Service Classification System (NESCS) (US EPA, 2015). This work places attention on the links between ecosystem types and the classification of beneficiaries from the final services supplied by those ecosystem types. Most recently, work on the classification of ecosystem services is underway in the context of the IPBES but this progress has not been reviewed from an accounting perspective at this stage.

5.69. The classification systems of CICES and NESCS can be seen as complementary. The CICES focuses on defining services following a hierarchical structure based on ecosystem service types, types of uses, and types of flows. The 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. The FEGS-CS provides a systemic approach to classification including types of ecosystems and types of use-beneficiary combinations.

5.70. One of the most important roles of a classification of ecosystem services is that it can be used to frame a discussion on the measurement and relative significance of ecosystem services. In effect, a classification can operate as a checklist and be applied in initial discussions by considering each ET and noting those ecosystem services that are considered most likely to be generated from that ET. The resultant "baskets" of services for each ET can aid in discussion of the role of accounting, the structuring of information, the assessment of resources required for compilation and generally communicating the message about the breadth of the relationship between ecosystems and economic and human activity.

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

5.72. There is common misunderstanding of the role of classifications with regard to the distinction between final and intermediate ecosystem services. Put simply, individual types of ecosystem services cannot always be neatly classified between those that contribute directly to economic units and those that reflect services provided between ecosystem assets. That is, it is not the type of ecosystem service that determines whether it is final or intermediate but rather the user of the service, either economic unit or ecosystem asset. Given this, for accounting purposes, work on classification must involve both the description of types of ecosystem services and an understanding of the users of different types of services.

5.73. A complete listing of 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. Where the user is also known, it is possible to classify distinctly the ecosystem services that are received by specific types of users. This is akin to the role of the Classification of Individual Consumption by Purpose (COICOP) that is used to classify only those products in the CPC that are the final consumption of households.

5.74. These considerations on the role of classifications, and the potential connections to related economic classifications, are important in 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, based on the considerations specified above, an important step is to identify and define the services and the associated benefits supplied by the ecosystem assets within an ecosystem accounting area. In this context, CICES, FEGS-CS and NESCS can be used as checklists. Further guidance is provided in Table 5.2 below, which describes examples of services and benefits that may typically be supplied. The definition of services and benefits in Table 5.2 is broadly aligned with the draft version of CICES 5.0. However, further discussion is necessary to develop an ecosystem service classification system that it is fully aligned with SEEA EEA while at the same time supporting application in other contexts. It is also noted that there may be a need to recognise differences at local and national level based on experiences in the testing of ecosystem accounting.

5.76. In Table 5.2, note that in all cases 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 harvested timber, i.e. the service is the accumulation of woody biomass in the ecosystem that is subsequently harvested. Accumulation of other biomass (e.g. in branches, below ground biomass, or in species that are not harvested) is not relevant for this service. In order to maintain that the physical output from the ecosystem equals the physical input in the economy (in the ecosystem services supply and use accounts), it is necessary that volume of wood/timber recorded is the same for both the service and the benefit - in those cases where it is appropriate to use harvested timber volume as indicator for both the service and the benefit. Felling residues are included in the service and the benefit. The felled timber enters the economy inclusive of felling residue, but these residues return immediately to the environment. These flows are termed natural resource residuals.

5.77. For timber harvesting, there is a difference in the time of recording of the ecosystem services depending on whether the growth of the tree is considered cultivated or natural. Cultivated biological resources are, for example, from plantations and natural resources are for example timber stands in natural forests. In reality, there is a grey line between the two, there are many ecosystems where management levels are intermediate (e.g. consider the well-known case of jungle rubber forests, where enrichment planting increases the density of rubber trees). This distinction is based on, among others, ownership and degree of control of the owner on the ecological processes (i.e. planting of seedlings, pruning, fertilizing, etc.). The SEEA Central Framework presents guidance on how to distinguish between these two levels of management for national accounting purposes.

5.78. In the case of both cultivated and natural 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, based on the expectation that the total accumulated biomass will be harvested (unless there are natural disasters such as fire, which can be recorded as 'other changes in volume' in timber stock). In the case of natural biological resources, the accumulation is recorded in total at the time of actual harvest of timber in the forest.

5.79. The reason for this difference in recording is that in the case of cultivated resources it is expected that all accumulated biomass is harvested at the end of the growing cycle. In the case of natural forest resources, only species of commercial interest are harvested (determined by timber species, age and quality of the individual trees, etc.). Hence it cannot be assessed a priori which parts of the annual accumulation of biomass is harvested in the case of natural resources. This is further elaborated below. The distinction between cultivated and natural biological resources facilitates integration with the SNA where the same distinction in the time 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 case of natural disasters. In the case of annual crops, it is proposed to record the annual harvest as a proxy for the ecosystem service provided. Also in this 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. By definition, the service is the *contribution* of the ecosystem to the service. In the case of services from ecosystems that are to a high degree natural, it is clear that the ecosystem's contribution is facilitating growth of the species that is harvested, be it a wild strawberry, medicinal bark, or a fish in the ocean. Since not all individual animals or plants that grow in the ecosystem are harvested, it is only meaningful to record the harvested animals and plants in the ecosystem services supply and use account. In the case of (semi-)-natural ecosystems, therefore, the service equals the benefit – in physical terms (e.g. expressed in cubic metres of timber or kilograms of fish).

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

Table 5.2: Examples of ecosystem services and associated benefits

Service (= the contribution of the ecosystem to the benefit)	*Benefit*	*Difference between service and benefit; 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 in terms of the volume of wood extracted from the forest at the point of time of harvest (i.e. felled biomass), and for timber from 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 in terms of the volume of wood that is harvested (i.e. the felled biomass), and for cultivated ecosystems (i.e. 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 and hence making the distinction between services and benefits is fundamental for valuation. In monetary terms the service can be measured in terms of the resource rent generated by the ecosystem – i.e. on the basis of the revenue of 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 (gross or net) value added.
Crop production: the contribution of the ecosystem to biomass accumulation of crops, i.e. the total and combined result of processes taking place in cropland that support crop production such as infiltration of water, the water holding capacity of the soil, the absorption of plant nutrients by soil particles and the resupply of these particles to plants.	Amount (e.g. tonnes) of harvested crops	In physical terms, there is no difference between the indicator for service (biomass accumulated) and the indicator for benefits (crops harvested). In monetary terms, the service can be valued in terms of the generated resource rent and the benefit in terms of revenue generated or (gross or net) value added (as explained in the cell above).
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 it is being 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 from the cropland 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, savannah).	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 the ecosystem and the economy, i.e. when biomass is grazed.	
Regulating services		
Climate regulation - Carbon sequestration. Assessments of this service should only consider carbon stored long-term (i.e. at least several decades) in the ecosystem.	Ecosystems provide climate regulation services through reduced concentrations of carbon dioxide in the atmosphere.	As a matter of convention, it is proposed to classify this service as a final service, since final and intermediate effects are very hard to disentangle. In some cases, there may be a revealed market in the purchase of carbon sequestration services by economic units.

Water retention. This may include for example water retention in soils (e.g. in upper watershed forests) and in flood retention basins (e.g. in wetlands)	Regulation of hydrological flow patterns including flood control	The service can be both final and intermediate.
Pollination	Increased crop biomass accumulation	Intermediate service. In some cases, this service is useful to quantify, in particular when ecosystems near croplands provide the pollination service by serving as a habitat for pollinators and when there is a need to specify the contribution of these ecosystems to economic production.
High water flow regulation (e.g. by mangroves, riparian vegetation, coral reefs)	Reduction in risk from 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 and reduced deposition of sediments 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)	In physical terms, all services and all benefits can be measured in terms of the number of people engaging in such activities. In monetary terms a resource rent approach can be used to value the service. In this case the costs of providing the service need to be taken into account, for instance in the case of recreation the labour and capital costs related to maintaining walking paths in natural parks.
Enabling nature-based recreation	Nature-based recreation (not involving overnight stays)	
Enabling nature-based education and learning	Nature-based education and learning	
Enabling nature-based religious and spiritual experiences	Nature based religious and spiritual experiences	
Enabling nature-based artistic and other human activities	Nature-based artistic and other human activities	

5.5 The role and use of biophysical modelling

5.5.1 Introduction

5.83. Biophysical modelling, in the context of this guidance document, is defined as the modelling of biological and/or physical processes in order to understand the biophysical elements to be recorded in an ecosystem account. These elements are part of either ecosystem asset measurement (including ecosystem condition and the ecosystem's capacity to generate services) or ecosystem services measurement. In this chapter, the focus is on ecosystem services.

5.84. The intention here is to provide some general guidance on the types of biophysical modelling approaches that can be used to analyse ecosystem service flows, as distinct from models that can be used to understand ecosystem processes (e.g. nutrient cycling, energy flows). In the scientific literature, a wide range of different modelling approaches has been described in the fields of ecology, geography and hydrology. Many of them are potentially relevant to ecosystem accounting depending upon the environmental characteristics, the uses of the ecosystem, the scale of the analysis, and the available data. It is impossible to describe all these different modelling approaches in one document. This section provides an overview of the different approaches, and their main uses for the biophysical modelling of ecosystem services.

5.85. An important aspect of applying biophysical models in ecosystem accounting is recognising the nature of the connections between ecosystem service flows and the condition of the relevant ecosystem asset. This connection is reflected in the concept of ecosystem capacity. Although the definition of ecosystem capacity remains a matter of ongoing discussion (see section 7.3), it is accepted broadly, that modelling 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 will generally involve a combination of spatial and spatial-temporal modelling approaches. Spatial modelling is required to produce maps of ecosystem services for a complete ecosystem accounting area. Spatial modelling 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 ARIES, MIMES, LUCI and InVEST (see e.g. Bagstad et al., 2013 for an overview and comparison of modelling tools). Several assessments of the relative strengths of these 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 the SEEA EEA framework.

5.88. Within the general GIS packages, spatial modelling tools that can be used to produce ecosystem services maps include look-up tables and interpolation techniques such as inverse distance weighting and kriging. In addition, specific GIS extensions such as Maximum Entropy modelling (Maxent) (Philips, et al., 2006) can be used. Lookup tables attribute specific values (e.g. of the amount of service supplied per hectare) to each EA. Inverse distance weighting algorithms are deterministic and predict values of un-sampled 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 characteristics of the pixels. 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. Critical in applying geostatistics is that a sufficiently large sample size is available, and that samples are representative of the overall spatial variability found. Examples of the applications of these approaches can be found in, for example, Karl (2010) in a study on rangeland ecosystem condition and Remme, et al. (2014) in a study of ecosystem services.

5.89. In ecosystem accounting, modelling is required to estimate the potential and capacity of an ecosystem to generate ecosystem services. The modelling approach that is consistent with coming to an understanding of flows of ecosystem services over time is a dynamic systems approach, which can also be applied in combination with spatial models. A dynamic systems approach is based upon modelling a set of state (level) and flow (rate) variables in order to capture the state of the ecosystem over time, including relevant inputs, throughputs and outputs. Dynamic systems models use a set of equations linking ecosystem condition or state, management and flows of 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 can contain non-linear dynamic processes, feedback mechanisms and control strategies, and can therefore deal with complex ecosystem dynamics. However, it is often a challenge to understand these complex dynamics, and their spatial variability, and data shortages may be a concern for ecosystem accounting that requires large scale analysis of ecosystem dynamics and flows of ecosystem services. In addition, operating costs and data requirements may be prohibitive to model a broad range of ecosystems services at fine resolution and in large areas. A potential way forward is to be selective in applying temporal models, e.g. by limiting modelling efforts to services that shown downward trends, and assume constant flows in time, at least initially, for services where such trends are not apparent.

5.91. Erosion and erosion control resulting from vegetation cover are often modelled with the USLE (Universal Soil Loss Equation), although its reliability in environments other than the landscapes and slope types for which it was developed (the United States) has proven to be variable. Other examples of process based models are the hydrological models such as SWAT (Soil and Water Assessment Tool) and SedNet from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). These models are both temporally and spatially explicit, and use a modelling approach integrated in a GIS environment.

5.92. If no data for specific ecosystem service flows is available, new data collection/generation (including inventories, remote sensing, spatial modelling and other sources) may be required. Data collection should be developed in a way that provides consistent estimates across the different service types (e.g. of similar detail, quality, error and uncertainties), as well as correctly embedded in the ecological and land use processes. Alternative modelling tools include:

- For soil and water-related process and service modelling tools consider SWAT, SedNet and others
- For carbon-related process and service modelling tools consider CASA (Potter, 1993), MODIS (MOD17) algorithm (Running, Nemani et al, 2004), BiomeBGC (Turner, Ritts et al, 2011) ORCHIDEE (Ciais, Wattenbach et al, 2010) and others
- For biodiversity and other service modelling tools where extrapolations of point (presence) data are relevant consider Maxent and others as described in Chapter 9.

5.6 Data sources, materials and methods for measuring ecosystem service flows

5.6.1 Introduction

5.93. SEEA EEA Annex A3 provides some stylised figures to help articulate the measurement required to estimate flows of ecosystem services. The figures included in that annex only relate to selected services but the basic logic of the models can be applied more generally. Of particular importance is recognising the distinction between the ecosystem service and the associated benefit.

5.94. Generally, it will be helpful for measurement purposes to distinguish between provisioning, regulating and cultural services. For this task, the use of a classification of ecosystem services, such as those described above, can serve as a useful checklist. Further, it is likely to be useful to consider the measurement of ecosystem services in relation to ecosystem types such as forests, wetlands, and agricultural areas.

5.95. A useful structuring of indicators is presented in Chapter 5 of the European Union's MAES project report (Maes et al., 2014). It presents indicators for different ecosystem services mapped across four broad ecosystem types – forest, cropland and grassland, freshwater and marine. A review of this material highlights the likely broad range of data sources that will need to be considered in generating a full coverage of ecosystem services.

5.6.2 Data sources

5.96. Data sources will be different in each country. It is suggested that important national data holders be engaged in the process of compiling the accounts. They will be able to advise on data availability and quality. The following list suggests some government departments (using generic titles) and the data they may hold:

- National Statistical Offices: agricultural production (crops and livestock); health statistics (incidence of environmentally-related diseases), population data, tourism data;
- Meteorological Agencies: rainfall, temperature, climate variables
- Departments of Natural Resources: timber stock and harvest; biomass harvest for energy; water supply and consumption; natural disaster statistics (floods, landslides, storms); land cover (to estimate carbon stock and sequestration); remote sensing (to estimate primary production);
- Water management and related agencies: water stocks and flows, abstraction rates, data from hydrological modelling;
- Departments of Agriculture: crop production, use of inputs in agriculture, erosion potential, biomass harvest;
- Departments of Forestry: forest stock and harvest; growth rates of forests, carbon sequestration;
- Departments of Environment and Parks: Iconic species habitats, visitors to natural areas, biodiversity.

5.97. Where national data are lacking, global datasets may be used. For instance, there are now several global datasets on soils such as the Harmonized World Soil Database and the ISRIC-WISE 3.1 soil profile database as well as global datasets on soil properties derived from these datasets (e.g. Stoorvogel, et al., 2016). There is also a global Digital Elevation Model that can be downloaded (http://www.gisat.cz/content/en/products/digital-elevation-model/aster-gdem) as well as several global datasets on forest cover, for instance from the Global Forest Watch. MODIS provides satellite derived, global information on a range of land, vegetation and water-related indicators at 250 to 1000m grid size, often multiple times per year (https://modis.gsfc.nasa.gov/). WaterWorld provides global information on various hydrological properties including rainfall and potential evapotranspiration at a 1 ha to 1 km^2 resolution (http://www.policysupport.org/waterworld). However, the accuracy of these products may typically be lower than national datasets and care needs to be taken in applying such datasets for national scale analyses (where feasible involving validation of the datasets).

5.98. Local academic and government researchers may have conducted studies for specific regions of the country or for specific services. As well, international organizations (e.g. UNEP, Secretariat for the CBD, World Bank) may have conducted studies on specific locations or services. These should also be reviewed and considered for integration into the ecosystem services supply and use account.

5.99. Databases storing research on ecosystem valuation will also include information on the physical aspects of the ecosystems they value. For example, if the fish harvest in one lake is estimated to generate US$50,000 per year, the research is likely to also include estimates of fish yields in physical units.

5.100. Two broad based ecosystem valuation databases that can be investigated for country-specific (or region-specific) biophysical data are the EVRI (Environmental Valuation Reference Inventory, at www.evri.ca) and the ESVD (Ecosystem Service Valuation Database at http://www.fsd.nl/esp/80763/5/0/50) that emerged from the TEEB (2010) study. Other service-specific or region-specific databases or projects should also be investigated. Note that the monetary valuations from these databases may not be appropriate for accounting purposes depending on the valuation concept applied (see discussion in Chapter 6).

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

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

- Ecological field studies to determine location-specific supply of ecosystem services. Such studies could, for example, collect data on water purification services of wetlands.
- Socio-economic surveys could be conducted to better understand how people and businesses use and value ecosystem services (e.g., water withdrawals, visits to recreational sites)
- Case studies could be conducted on target populations (e.g., households near forest areas) to better understand their use of ecosystem services (e.g., biomass for fuel, food gathering, sources of water).

5.103. While there is an increasing amount of information and examples of measurement of ecosystem service flows, a challenge is likely to lie in adapting, integrating and scaling the available information from multiple sources for ecosystem accounting purposes. The issue of scaling is considered below. From a practical perspective, it is sufficient to note here that, when accounting for multiple ecosystem services, the aim must be to measure the supply of ecosystem services for multiple ecosystem assets and types, and also over a series of accounting periods. As appropriate, adjustments to ensure that measures of different ecosystem services relate to common spatial areas and the same time periods should be made.

5.6.3 Measuring the supply of ecosystem services

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

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

5.106. For regulating services, some specific suggestions for measurement using bio-physical models are suggested in Table 5.3 (from Hein, 2014). These suggestions are intended as starting point for research and testing only.

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. Relevant considerations are in the following sub-section.

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

Ecosystem Service	Potential metric	Description
Climate regulation - carbon sequestration	Ton of carbon (or carbon-dioxide) sequestered per year, per hectare or per square kilometre.	There are two basic approaches to analyse 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. It is also possible to estimate flows of carbon, although this method is prone to considerable uncertainty. In this case, carbon sequestration can be related to net ecosystem productivity (NEP), i.e. the difference between net primary productivity (NPP) and soil respiration. Carbon sequestration rates in specific ETs can be derived from literature and from IPCC based greenhouse gas inventory estimates for the LULUCF, and used to produce look-up tables. NPP can also be derived from the Normalized Difference Vegetation Index (NDVI) that can be measured using remote sensing images. However, care needs to be taken that the relationship between NDVI and NPP is well established for the ecosystems involved, and that accuracy levels are calculated based on sample points. NPP can be combined with estimates of soil respiration to estimate carbon sequestration by pixel. However, it is often difficult to find credible values for the spatially very variable soil respiration rate, which depends on bacterial and fungi activity which are in turn guided by the local availability of organic matter (e.g. fallen leaves), temperature, moisture, etc.
Maintaining rainfall patterns	mm water evapotranspiration per hectare per year, mm rainfall generated per hectare per 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% 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. This is a significant ecosystem service, however, the value of individual pixels is difficult to establish since it requires understanding large scale, complex climatological patterns, large scale analyses of potential damage costs, and interpolations of values generated at large scales to individual pixels with detailed climate-biosphere models.
Water regulation	- water storage capacity in the ecosystem in m3 per hectare (or in mm); - difference between rainfall and evapo-transpiration in m3/ha/year;	Water regulation includes several different aspects, including (i) flood control; (ii) maintaining dry season flows; and (iii) water quality control – e.g. by trapping sediments and reducing siltation rates. Temporal, i.e. inter-annual and intra-annual, variation is particularly important for this service. Modelling this service is often data-intensive and also analytically complex. It generally requires the use of hydrological models. Particular challenges are finding streamflow and other data to calibrate the models and, at aggregated scales, securing sufficient computing power.

Storm and high water protection	Surface water modelling can be deployed to analyse reductions in flood risk, expressed either as reduction in probability of occurrence, reduction in average duration of the flood, or reduction in water level depending on context	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 modelling flood patterns and the influence of the 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 understand the monetary value of the service - in particular in those areas where it is certain that natural systems, if lost, would be replaced by artificial ones (e.g. a dyke), as would be the case in most of the Netherlands, for instance. In this case, valuation may be done on the basis of a replacement cost approach that does not require understanding the physical service in full.
Erosion and sedimentation control	The difference between sediment run-off and sediment deposition in ton/ha/year in the current ecosystem state compared to a situation with no plant cover	There is relatively much experience with modelling this service. Erosion models can be integrated in catchment hydrological models (such as SWAT or CSIRO SedNet, both freeware) to predict sediment rates. In SWAT, a watershed is divided into Hydrological Response Units (HRUs), representing homogeneous land use, management, and soil characteristics. Erosion rates need to be estimated for each HRU, for instance on the basis of the MUSLE or RUSLE erosion models or alternatively SWAT landscape can be used which includes grid based land cover units.
Water purification	Amount of excess nitrogen and or phosphorous removed in the ecosystem	Various hydrological models, including SWAT include modules that allow estimating the nutrient loads in rivers as a function of streamflow, discharge, temperature, etc. Nitrogen is broken down by bacterial activity, phosphorous is typically removed in ecosystems by binding to the soil particles. Modelling these processes requires large datasets, preferably with daily time-steps, of nutrient concentrations in various sampling stations along the river course.

Source: Adapted from Hein, 2014.

5.6.4 Recording the users of ecosystem services

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

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

- Industry groupings whereby individual establishments or businesses are grouped into those that undertake similar activities such as agriculture or manufacturing.
- Allocation of use of ecosystem services by household income levels
- Distinguishing between rural and urban use of ecosystem services
- Distinguishing between those services that are used locally, nationally or globally.

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

5.111. When measuring the supply of ecosystem services and mapping out the supply across ecosystem types (e.g. forests), it is likely to be useful to consider the link to users. This approach has been extensively applied in the development of FEGS-CS and NESCS by the US EPA (Landers and Nahlik, 2013; US EPA 2015).

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

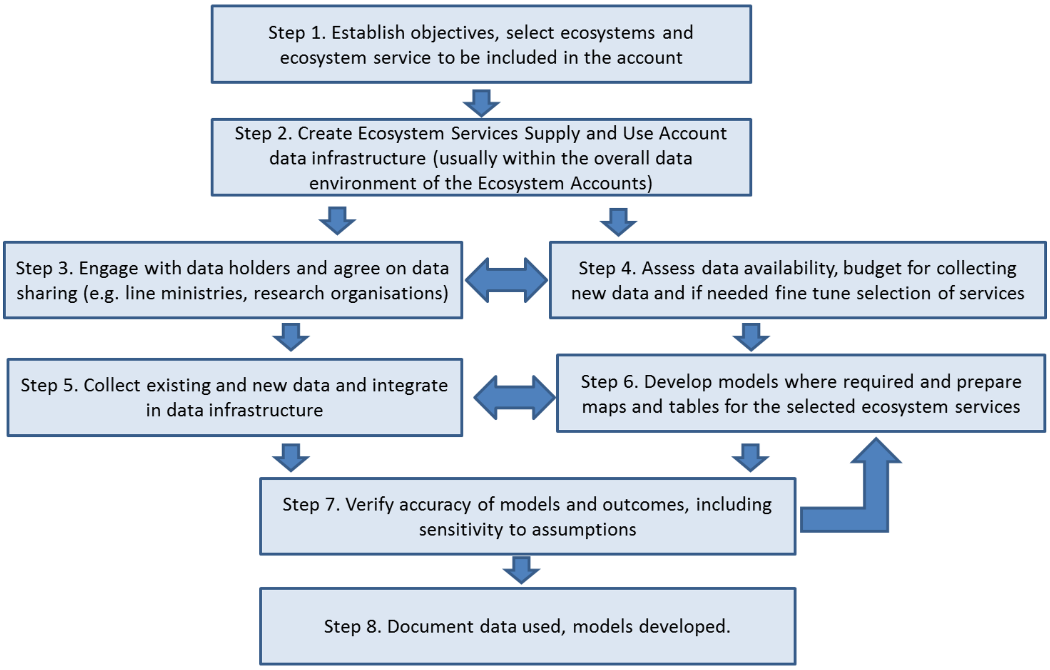
5.7 Recommendations for the measurement of ecosystem services

5.113. A practical approach to developing ecosystem service supply and use accounts will in many cases involve a gradual approach starting with the inclusion of a selection of ecosystem services. Whether a minimum, partial or fully spatial approach is adopted, it is likely that a step-by-step approach focusing initially on a limited set of ecosystem services will be most practical. This limited set can, over time, be expanded to a more comprehensive set of services. The selection of the first set of services will generally depend upon policy priorities, data availability and the computational complexity of analysing the service.

5.114. A flow chart describing the general steps with regard to measuring ecosystem services for compilation of the ecosystem services supply and use account is provided in Figure 5.1 below. Crucial to undertaking ecosystem accounting is that it is not meant to be a one-off exercise. Developing the ecosystem services models will take time and over time existing models can be refined and new models can be developed. As an integral part of steps 3 to 7, there is a need to identify data and knowledge gaps, 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 much of the data needed to compile ecosystem services supply and use accounts needs to come from models, including process models and models to inter and extrapolate data. There are several obligations inherent in the use of such data, in particular complete transparency about the models and the particulars of equations, their statistical significance, data used and quality of the data. The integrity of the accounts is undermined if such information is not included along with such data. In addition, a clear and detailed description of data and models used is essential to support the process whereby accounts are being regularly updated and improved, also in view of staff changes that may take place in NSOs and research organizations supporting the production of the accounts.

Figure 5.1: Flow chart for producing an ecosystem services supply and use account.



5.116. For countries seeking to undertake pilot studies in ecosystem accounting, the most appropriate initial advice is that there is likely to be a large body of work within each country that can be used as a basis to estimate flows of ecosystem services. At the same time, it is unlikely that estimates of ecosystem services for specific ecosystems in each country will have been developed in a relatively standardised way. Consequently, it is the role of the ecosystem accountant to bring together the available expertise and research. Advancing the measurement of ecosystem services in the short term is thus a matter for testing rather than primary research.

5.117. Once a set of priority services has been determined it will be relevant to quantify and map the ecosystem services in terms of both ecosystem services supply (from ecosystem units) and use (by users, including businesses, households and governments). Relevant data sources and modelling techniques are described in sections 5.5 and 5.6 above.

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

5.119. It is recommended that the ecosystem accounting framework be used to build an understanding of the gaps in information, either because certain ecosystem services have not been measured or because ecosystem services from certain ecosystem types have not been measured. The accounting framework can play an important role in identifying data gaps and supporting a discussion of priorities for additional data collection.

5.120. Identifying data gaps may be done by determining a list of priority ecosystem services based on existing national land and water management, and nature conservation practices. For this task:

- The US EPA FEGS-CS or NESCS can be applied as analytical tools as they 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 check-lists.

5.121. Depending on the nature of the data gaps, the use of benefit transfer functions may be considered and cautiously tested. Generally, it will be important to develop an understanding of uncertainties when defining, classifying, quantifying and mapping ecosystem services and to prepare validation/quality control data and protocols.

5.8 Key areas for research

5.122. Notwithstanding the priority for testing to be the focus of current activity, there are some areas of research that would support this testing work. Primary among these is resolution of issues concerning the definition and classification of ecosystem services. This work has advanced well and the relevant boundary issues are quite well delineated. However, further consultation leading to decisions or treatments is needed to put in place a classification of ecosystem services that is, at least, appropriate for ecosystem accounting purposes.

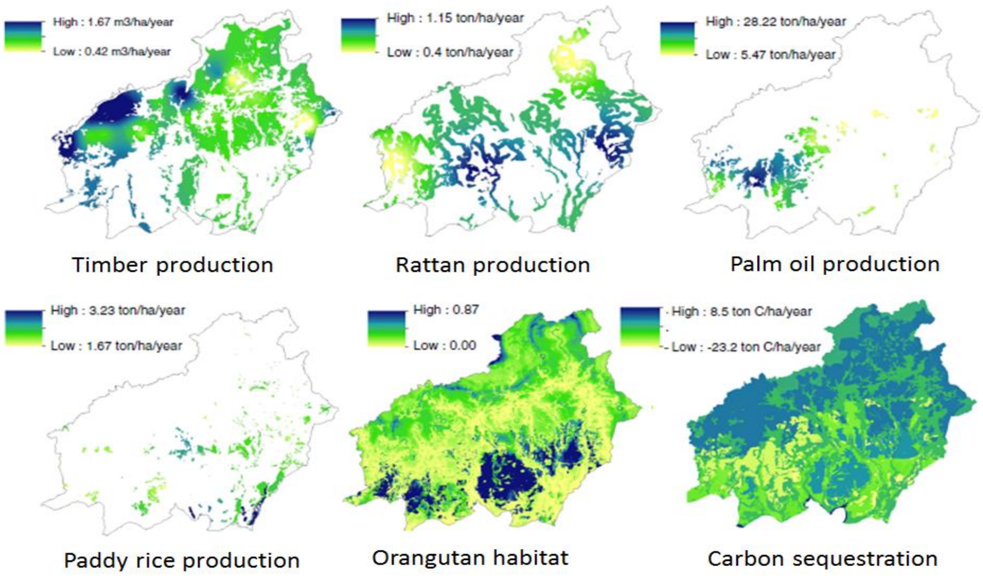
5.123. The second key area of research is articulation of the treatment and measurement of intermediate services in ecosystem accounting. A related task is specifying what are best called ecological production functions or value chains – i.e. the sequence of ecosystem processes, possibly across ecosystem types, that leads to the supply of a final ecosystem service. Although it is not anticipated that a complete catalogue of all such production functions would be established in the short to medium term, research in this direction would be of direct benefit to applying ecosystem services and ecosystem accounting measures to policy questions. Examples of relevant ecological processes include rates of growth (e.g. of timber), decomposition, soil erosion, habitat fragmentation, water runoff and yield.

Box 5.1: Ecosystem services mapping in Central Kalimantan

In a 2014 PhD project at Wageningen University, seven ecosystem services were mapped following the SEEA EEA in Central Kalimantan province, Indonesia for the year 2010. Mapping the seven selected ecosystem services required a specific dataset for each service. The data were collected from a variety of sources including from existing land cover maps soil maps, Digital Elevation Models, topographic and hydrological maps. The land cover map, topographic map, and hydrological map are available in vector format. All spatial input data were converted to raster format with a pixel size of 100 m for further spatial analysis. Spatial data were combined with Indonesian statistical data 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 as much as possible ecosystem services data from 2010 was used. However, for some services data from 2009 or 2011 was 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 $R^2<0.2$ for all provisioning services). The explanation for this may be that there is no strong correlation between ecosystem properties and extraction rates of provisioning services, and that extraction rates are an overriding factor that determine flows of provisioning services. Therefore, in order to produce wall-to-wall mapping of ecosystem services, different spatial modelling techniques were used. These included lookup tables, interpolation, regression modelling, and probabilistic models such as Maxent.

Provisioning services are commonly supplied in only one land cover class, but within these land cover classes there can be substantial variation in supply. Provisioning services were therefore mapped using spatial interpolation instead of using lookup tables (which results in a specific value for a given land use class). Interpolation was carried out in ArcGIS using ordinary kriging. Note that the habitat service is included as a service in the map, expressing both biodiversity and potential to support tourism. This service was mapped with Maxent. For carbon, there were insufficient observations to pursue spatial interpolation, even though it is likely that spatial variation within ecosystem types also occurs. Therefore, for carbon sequestration, a lookup table was used. This table specifies the amount of carbon sequestration in each ecosystem type based on values found in the scientific literature.



Source: based on Sumarga and Hein, 2014. Mapping ecosystem service s for land use planning, the case of Central Kalimantan. Environmental management 54, 84-97 and Sumarga et al., 2015. Mapping monetary values of ecosystem services in support of developing ecosystem accounts. Ecosystem Services 12,71–83.

6 Valuation in ecosystem accounting

Key points in this chapter

The estimation of monetary values for ecosystem services and ecosystem assets can be undertaken for a variety of purposes. It is essential that the purpose of valuation is well understood.

In ecosystem accounting, the primary purpose of valuation in monetary terms is the integration of information on ecosystem condition and ecosystem services with information in the standard national accounts. This provides information to support comparison of ecosystem services with the production and consumption of other goods and services and supports the use of ecosystem information in standard economic modelling and productivity analysis.

For this purpose, the valuation concepts and approaches used for ecosystem accounting need to be consistent with the valuation concept used in the national accounts – i.e. exchange values. Exchange values are those values that 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 the estimation of welfare based values and the use of non-monetary valuation techniques. Although these valuation concepts should not be applied to derive monetary valuations for ecosystem accounting, the broader ecosystem accounting model showing the relationships between ecosystem assets, their condition and the services supplied will still be relevant. Wherever possible a common underlying dataset on ecosystem stocks and flows in physical terms should be used to underpin valuation studies, irrespective of the valuation concept and purpose being applied.

Recent investigation into the potential to use the range of non-market environmental valuation techniques suggests that many are relevant or may be adapted for use in accounting. Nonetheless, much further discussion and testing on the use of valuation methods for the estimation of exchange values is required.

In ecosystem accounting, the valuation of ecosystem services is the starting point for the valuation of ecosystem assets. A clear distinction should 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. This occurs for many reasons. For some, the concerns about valuation relate to the implication that a “dollar value” is placed on all environmental assets and services and that this is both inappropriate and misleading. For others, the measurement concerns are too great and the environment is considered too complex to suggest that useful measures in monetary terms might be compiled. Finally, there are differences concerning the purposes, concepts and techniques in relation to monetary valuation.

6.2. As in SEEA EEA chapter 5, the ambition in this chapter is to provide a possible pathway through these various issues, such that the discussion on valuation for ecosystem accounting can be placed in context with other approaches and perspectives.

6.3. One general conclusion is that valuation in monetary terms requires careful consideration of the *purpose* of the valuation. Alternative purposes include accounting purposes and the assessment of changes in welfare between alternative scenarios. Once the purpose is defined, the appropriate valuation *concept* can be selected and from this, the relevant valuation *method and technique* can be applied. Often the discussion in environmental valuation moves directly to discussion of method and technique without recognising that different purposes for valuation, and hence different valuation concepts may be relevant.

6.4. It is clear that the majority of work in this area of valuation has been motivated by the assessment of trade-offs between different potential land uses and in this context monetary valuation of ecosystem services has a particular interest in measuring differences in economic surplus associated with different scenarios, following a standard cost-benefit type methodology. Other work has been focused on the measurement of shadow prices for ecosystem assets taking into account relevant externalities. Given these analytical perspectives for many involved in the ecosystem services valuation space, the focus on exchange values of ecosystem services for accounting purposes may appear inappropriate or irrelevant.

6.5. However, accounting is designed to support a different analytical and policy perspective, in particular to encourage and support the use of environmental information in standard economic and financial decision making. In this context, the measurement of the value of ecosystem services in exchange values support direct integration with standard financial and national economic accounting data. Consequently, 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 consider ecosystems through multiple analytical lenses appears a strong motivation to continue development of valuations for accounting purposes.

6.6. A fundamental aspect of valuation in an accounting context is that the first step is the valuation of individual ecosystem services. In general, this will require finding an appropriate monetary value to apply 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. visitor to a forest).

6.7. Valuing ecosystem assets is a distinct task. For a comprehensive valuation, it requires estimation of the future flows of ecosystem services that are expected to be supplied by an ecosystem asset. In some cases, for example agricultural land, observed market values for land will be able to be related to the value of ecosystem assets but these prices will likely 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 the step of valuing individual ecosystem services.

6.8. This chapter is structured in the following way. In section 6.2 the main valuation principles for ecosystem accounting are outlined drawing out the key points from the material presented in SEEA EEA chapter 5 and incorporating a range of considerations that have emerged since that time. Section 6.3 considers relevant data and source materials and in section 6.4 the key challenges in valuation are described. The final section provides a summary of recommendations in relation to valuation based on current practice and knowledge and a summary of the key issues requiring further research. Recognising the distinct nature of the task of valuing ecosystem asset, the issues related to the valuation of ecosystem assets and the valuation of ecosystem degradation are discussed in Chapter 7.

6.2 Valuation principles for ecosystem accounting

6.2.1 Introduction

6.9. SEEA EEA recognises that the term valuation can mean different things. For accountants and economists, valuation is almost always used in the context of placing a monetary value on assets, goods or services. In other contexts, valuation may refer to a more general notion of recognising significance or importance. In SEEA EEA, the focus is on valuation in monetary terms but this is not to discount the role or importance of other concepts of value. Indeed, accounting for ecosystem condition and ecosystem services in physical terms may provide a relevant information base for non-monetary valuation. (A useful introduction to different concepts of valuation including both monetary and non-monetary valuation is provided in IPBES (Pascual, et al., 2017), see also Maynard et al. (2014)).

6.10. Monetary valuation in the SEEA EEA is applied to the valuation of ecosystem services and the valuation of ecosystem assets. The relevant valuation concept for ecosystem accounting is exchange values.[30] 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 ecosystem assets). Since many transactions with ecosystems are usually not reflected in observed exchanges of money, these exchange values must be estimated using non-market valuation techniques. There are some exceptions where payments are made to owners of resources (e.g. stumpage fees paid by the forestry industry) and depending on the nature of the payments these may reflect values for associated ecosystem services.

6.11. The development of techniques for non-market environmental valuation is well-established and broad ranging. The extent of development is reflected in key publications including Freeman (2013) and Champ et al. (2017). From a national accounts perspective, the work on environmental valuation has commonly been characterised as inappropriate because the techniques are often applied to answer questions concerning the change in welfare associated with different environmental situations. Indeed, the SEEA EEA adopted this characterisation in aligning environmental valuation with the estimation of welfare values, a concept distinct from exchange values required for accounting.

6.12. As the discussion between experts in environmental valuation and national accountants has progressed in recent years, there is clear evidence of far more common ground that has been identified in the past. This is not to say that path forward will be straightforward, but there are strong grounds to imagine that the research and development in environmental valuation by economists can be adapted for use in accounting contexts. Research to understand and document the common ground and remaining challenges is currently underway in the context of a World Bank WAVES project. A paper examining the connections between these two perspectives on valuation has been prepared as part of the WAVES Partnership program of research (Atkinson and Obst, 2017). This chapter picks up on some of its key findings, recognising that further discussion and investigation will be required.

6.2.2 Establishing the markets for exchange values

6.13. As noted, underpinning the estimation of exchange values is the notion that there is a transaction or exchange between ecosystem assets and economic units, businesses, governments and households, that could be imagined to occur in a market setting. Since the ecosystem assets themselves are not actual market participants, the challenge in valuation for accounting lies in establishing the assumptions about the institutional arrangements that would apply if there was an actual market involving ecosystem assets.

6.14. One way of considering this is to find parallels between existing markets and transactions in ecosystem services. Some ecosystem services can be reasonably closely connected to activities in markets. This is generally the case for provisioning services where ecosystem services that contribute to the production of food, fibre, fuel and

[30] The term exchange values was introduced in the SEEA EEA since the term market prices as used in the SNA is often misunderstood to mean that national accounting only incorporates values of goods and services transacted in markets. An alternative term for the target valuation concept is transaction price. This term may be substituted for exchange values without loss of meaning.

energy can be valued using observed values for the associated marketed products. Here a close connection can be made to the values used in the SNA to estimate production and consumption. One description of these types of ecosystem services is that their values are “near-market” (Nordhaus, 2006; Farley, 2008). In this context, the implicit assumption is that the institutional arrangements underpinning the exchanges of ecosystem services are the same as for the 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 ecosystem services that may be considered to provide public goods – e.g. the contribution of ecosystems to flood protection. In these cases, determining valuation techniques for the estimation of exchange values is more complicated since the nature of the appropriate institutional arrangements is not clear.

6.16. In standard national accounting, the values that are recorded do not rely on making specific assumptions regarding institutional arrangements. That is, 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 equally whether in open or regulated market situations.

6.17. While being open to recording observed exchanges in all market structures, this however does leave 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 are relatively pragmatic in such contexts and are likely to consider what market arrangements are most likely given the country, the likely behaviour of market participants, existing tax and regulatory settings and the type of ecosystem service. Since accountants will make these types of assessments looking back in time (accounting records past events), the estimation context is somewhat different from making these types of assumptions with respect to future behaviour or alternative scenarios.

6.18. The key point here is to recognise that national accountants are aiming to estimate a value that would have been revealed in the “most likely” institutional arrangements. A useful topic for research with non-market valuation specialists would 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 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 estimating a demand curve which delineates combinations of prices and quantities that would satisfy a given set of consumers. Conceptually, somewhere along the demand curve lies a point at which a supplier is willing to provide the goods or services and the intersection represents an exchange value. This line of thinking opens up a path towards linking standard non-market environmental valuation techniques with the requirements of national accounting. These possible connections are described further in the following sections.

6.20. Making the connections between welfare values and accounting values will depend on clarifying the assumptions regarding institutional arrangements. As noted above, national accountants need to provide more clarity in this area to engage effectively recognising that this is a key focus of work on non-market valuation from an economist's perspective. By way of example, Day (2013) observed that under the assumption that ecosystem assets are perfectly price discriminating – i.e. as suppliers they charge exactly what each user is willing to pay, consumer surplus is eliminated and the estimated prices reflected in the demand curve will each be exchange values. 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, there may not be support for using this specific behavioural assumption, but the general point remains. Overall, both economists and accountants need to consider demand and supply factors in estimating exchange values.

6.21. One concern about the use of exchange values, and hence the exclusion of consumer surplus is that it is likely to generate relatively lower values for ecosystem assets which are more distant from economic units and will also not incorporate potentially important non-use values. There are also ecosystem services where a relatively high share of the welfare generated is in the form of consumer surplus. For instance, in the case of air filtration an important part of the generated welfare can be related to avoided sickness and avoided premature mortality resulting from air pollution. In this case, the accounts would provide a lower value for this service (notwithstanding the potential to record significant direct economic effects through reduced health costs and productivity), compared to the higher welfare value that will consider the value of additional life years, for example (see e.g. Remme et al., 2015 for a detailed example).

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

6.23. This is consistent with current situation in the use of the national accounts where monetary values also do not necessarily reflect welfare generated. For example, the values recorded in the national accounts for the production and consumption of education do not reflect the full welfare arising from this consumption. This is especially so when education is provided by the public sector. The use of exchange values to underpin macro-economic measurement and modelling is accepted, as is the relevance of estimating welfare values in making decisions, for example in 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 area for further discussion and investigation is whether a complementary set of ecosystem accounts in monetary terms might be compiled using non-exchange value concepts. The starting logic would be that complementary accounts could be based on the same biophysical accounts (for ecosystem extent, condition and service flows) and then alternative valuation concepts could be applied to support particular policy contexts. Discussion will need to consider not only the feasibility and relevance of such an approach but also how a set of complementary accounts would be placed in context with 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. These flows are then multiplied by a relevant value in order to estimate the monetary value of the flows. 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 analyse ecosystem services. From an aggregate perspective, the common starting points will be information on production and income from national accounts, economic statistics, trade data, tourism activity statistics, price index data and similar types of statistical and administrative data. While these datasets will not provide direct estimates of values for ecosystem services, they will provide a strong base 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 understanding spatial patterns of ecosystem services supply and use. This is particularly the case for regulating services. Often, supply and use take place at distinct locations. For example, a forest may filter air but the users of this service may be people living nearby the forest. Note that where a fully-spatial approach is pursued, there is also the need to spatially allocate aggregate values of services in order to produce maps of ecosystem services values (see e.g. Remme et al., 2015 and Sumarga and Hein, 2014).

6.28. Where resources are not available to undertake primary data collection, it will be necessary to find valuation studies that have estimated values for the relevant ecosystem service for particular ecosystem types. There are a number of databases that hold relevant studies, including the Ecosystem Services Valuation Database (ESVD) that has built on the original work of the TEEB study, the Environmental Valuation Reference Inventory (EVRI) database, and the Ecosystem Valuation Toolkit by Earth Economics. A useful link to these and other valuation databases is on the Ecosystem Services Partnership website (see http://www.fsd.nl/esp/80136/5/0/50).

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 these studies will require careful consideration. Generally, it will be necessary to apply benefit transfer methods in which the results from on study are applied in other contexts. The critical question is the extent to which the contexts are comparable in terms of: (i) similarity of ecosystem assets and their services; (ii) valuation purpose and decision context; and (iii) similarity of likely institutional arrangements. In addition, it will be important to understand the connection to any underlying biophysical data and the scale at which these data have been estimated, for example, through biophysical modelling. There is a range of approaches to benefit transfer and some are preferable to others. An introduction to this material is provided in SEEA EEA Chapter 5 and a longer discussion of alternative benefit transfer methods is provided in, for example Plummer (2009) and Barton (2015).

6.30. A general caveat on the use of existing studies for the valuation of ecosystem services (that applies equally with respect to benefit transfer approaches), is that the materials are usually not explicit about the valuation concept being applied. Hence, it is often unclear as to 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 5, these materials should provide a reasonable starting point for investigating the valuation of ecosystem services for ecosystem accounting.

6.31. The process outlined here for the valuation of ecosystem services can be applied to estimate the value of ecosystem services in monetary terms for a single ecosystem service from a single ecosystem asset or ecosystem type. However, in a SEEA EEA context, the general ambition is to estimate values for multiple ecosystem services across multiple ecosystem assets and ecosystem types. Where compilation extends to this scope, then by applying the valuation techniques described in the following sub-section, the compilation of an ecosystem services supply and use account in monetary terms is possible. This account has the same structure as the ecosystem services supply and use account in physical terms presented in Chapter 5, Table 5.1. Thus, estimates for individual ecosystem services are presented together and estimates are recorded for both the supplying ET and the receiving users. As for the physical supply and use table it is appropriate, and likely necessary, to understand both the supply and the use of ecosystem services to best compile this table 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 measuring the same valuation concept. However, it should be recognised that different techniques may generate substantively different estimates of value and care should be taken in quality assuring all estimates whatever technique is used.

6.32. Additional support for applying valuation in national accounting contexts can be found in materials from the UNEP Ecosystem Services Economics unit, the materials developed as part of the TEEB study, work being undertaken within the World Bank WAVES project and the discussion of valuation in the context of the IPBES.

6.3.2 Potential valuation techniques

6.33. A number of valuation techniques have been considered appropriate for measuring exchange values. However, there is ongoing discussion on this topic to build stronger levels of understanding in the use of standard non-market environmental valuation techniques for accounting purposes. The SEEA EEA Chapter 5 outlines a number of the techniques and an updated summary of valuation techniques is provided in Table 6.1.

6.34. Table 6.1 presents a number of standard techniques in the left-hand column following the structure of the discussion in the SEEA EEA. Ideally, it would be possible to provide more specific guidance on valuation techniques by type of ecosystem service – i.e. showing different ecosystem services in the left-hand column. At this stage, clear advice relating to recommended valuation techniques for individual ecosystem services has not been discussed or developed but it is the intended direction. Progress towards this objective will be considerably supported through progress in the discussion of classifications of ecosystem services. This will mean that a discussion on valuation techniques can be aligned around a common description of individual ecosystem services. It is clear that different descriptions of ecosystem services can lead to quite alternative valuation considerations.

Table 6.1: Summary 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 will be affected by the property rights and market structures surrounding production. For example, open access fisheries and markets for water supply often generate low or zero rents.	In principle, this method is **appropriate** but care is needed to ensure that the residual estimated through this approach is limited to the target ecosystem service	Provisioning services involving harvest or abstraction (e.g. concerning timber, fish, crops, livestock, etc.) Potentially, also applicable to cultural services such as recreation provided by established businesses.
Production function, cost function and profit function methods	Prices obtained by determining the contribution of the ecosystem to a market based price using an assumed production, cost or profit function.	In principle, analogous to resource rent but generally can be better targeted to focus only on specific ecosystem services and models more able to take into account ecological connections. However, likely more data intensive and require benefit transfers methods for higher level aggregates.	**Appropriate** provided the market based price being decomposed refers to a product rather than an asset – e.g. value of housing services rather than the value of a house.	Prices for all type of ecosystem services may be estimated using this technique provided an appropriate production or similar function can be defined. This will require that the ecosystem services are direct inputs to the production of existing marketed goods and services. It is likely to be of most relevance in the estimation of prices for provisioning services and for certain regulating services that are inputs to primary production, e.g. water regulation.
Payment for Ecosystem Services (PES) schemes	Prices are obtained from markets for specific regulating services (e.g. in relation to carbon sequestration)	Estimates will be affected by the type of market structures put in place for each PES (see SEEA EEA 5.88-94)	**Possibly appropriate** depending on the nature of the underlying institutional arrangements.	Given the most common focus of PES schemes, the price information will be most applicable to the valuation of regulating services, e.g. carbon sequestration.
Hedonic pricing	Prices are estimated by decomposing the value of an asset (e.g. a house block including the dwelling and the land) into its characteristics and pricing each characteristic through regression analysis	Very data intensive approach and separating out the effects of different characteristics may be difficult, unless there are large sample sizes.	**Appropriate in principle**, if an individual service can be identified. Heavily used in the pricing of computers in the national accounts.	Most commonly applied in the context of decomposing house and land price information and hence will be relevant for those ecosystem services that impact on those prices. Examples include access to green space, amenity values and air filtration. A challenge is attributing the estimated prices to the location of supply.
Replacement cost	Prices reflect the estimated cost of replacing a specific ecosystem service using produced assets and associated inputs.	This method requires an understanding of the ecosystem function underpinning the supply of the service and an ability to find a	**Appropriate** under the assumptions (i) that the estimation of the costs reflects the qualities of the ecosystem services being lost; (ii) that it is a least-cost treatment; and (iii) that it	The idea of replacement cost assumes that a service can be replaced, i.e. that a man-made alternative can be developed. In general, this engineering type focus will mean that the method would be applied for various

		comparable "produced" method of supplying the same service.	would be expected that society would replace the service if it was removed. (Assumption (iii) may be tested using stated preference methods and should take into account the potential scale issues in replacing the service.)	regulating services such as water regulation, water purification and air filtration.
Damage costs avoided	Prices are estimated in terms of the value of production losses or damages that would occur if the ecosystem services were reduced or lost due to ecosystem changes (e.g. as a result of pollution of waterways).	May be challenging to determine the value of the contribution/impact of an individual ecosystem service.	**Appropriate** under the assumptions (i) that the estimation of the damage costs reflects the specific ecosystem services being lost; (ii) that the services continued to be demanded; and (iii) that the estimated damage costs are lower than potential costs of abatement or replacement.	Similar to replacement costs, the focus will generally be on services provided by ecosystems that are lost due to human activity impacting on environmental condition, particularly through pollution. Regulating services are likely to be the most commonly estimated using this method.
Averting behaviour	Prices are estimated based on individual's willingness to pay for improved or avoided health outcomes.	Requires an understanding of individual preferences and may be difficult to link the activity of the individual to a specific ecosystem service.	**Possibly appropriate** depending on the actual estimation techniques and also noting the method relies on individuals being aware of the impacts arising from environmental changes.	
Restoration cost	Refers to the estimated cost to restore an ecosystem asset to an earlier, benchmark condition. Should be clearly distinguished from the replacement cost method.	The main issue here is that the costs relate to a basket of ecosystem services rather than a specific one. More often used as a means to estimate ecosystem degradation but there are issues in its application in this context also.	**Likely inappropriate** since it does not determine a price for an individual ecosystem service but may serve to inform valuation of a basket of services.	
Travel cost	Estimates reflect the price that consumers are willing to pay in relation to visits to recreational sites.	Key challenge here is determining the actual contribution of the ecosystem to the total estimated willingness to pay. There are also many applications of this method with varying assumptions and techniques being used with a common objective of estimating consumer surplus. Finally, some travel cost methods include a value of time taken by the household which would be considered outside	**Possibly appropriate** depending on the actual estimation techniques and whether the approach provides an exchange value, i.e. excludes consumer surplus. A distinction here is that the total of actual travel costs is not a measure of the value of the ecosystem services but it may be appropriate to use the demand profile associated with the travel cost (the estimation of this demand curve is	This will relate to valuation of recreational ecosystem services.

		the scope of the production boundary used for accounting purposes.	referred to as use of the travel cost method).	
Stated preference	Prices reflect willingness to pay from either contingent valuation studies or choice modelling.	These approaches are generally used to estimate consumer surplus and welfare effects. Within the range of techniques used there can be potential biases that should be taken into account.	**Inappropriate** since does not measure exchange values. However, while the direct values from stated preference methods are not exchange values, it is possible to estimate a demand curve from the information and this information may be used in forming exchange values for ecosystem services.	
Marginal values from demand functions	Prices are estimated by utilising an appropriate demand function and setting the price as a point on that function using (i) observed behaviour to reflect supply (e.g. visits to parks) or (ii) modelling a supply function.	This method can use demand functions estimated through travel cost, stated preference, or averting behaviour methods. The use of supply functions has been termed the simulation exchange value approach (Campos & Caparros, 2011)	**Appropriate** since aims to directly measure exchange values. However, the creation of meaningful demand functions and estimating hypothetical markets may be challenging.	In principle, may be applied for many types of ecosystem services but most likely to be relevant in the estimation of values for regulating and cultural services.

6.3.3 Alternatives to direct monetary valuation

6.35. The discussion in this chapter has a focus 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 these services.

6.36. For instance, governments may be interested in the resource rent generated by different ecosystems under current management, but they may also be interested in, for example, the net value added and employment that is generated in sectors dependent upon services provided an ecosystem, as in the case of a 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 compared to resource rent alone.

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

6.4 Key challenges and areas for research in valuation

6.38. There is a wide range of challenges in valuation. The following section describes those that may be most commonly confronted beyond the issues already raised in this chapter. Some of these will be particular targets for research work.

6.39. The target of valuation. In the SEEA EEA, the ecosystem accounting model (see chapter 2) has a clear distinction 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. In fact, the market price reflects the value of the benefit and estimating the appropriate value for the associated ecosystem service must involve deducting the costs of extraction and harvest, thus leaving a residual that reflects the ecosystem contribution.

6.40. By way of example, in the case of timber harvest there will commonly be a price for the logged timber – perhaps a roadside price. This price should be sufficient to cover the costs of felling (labour, fuel, equipment, land management costs, etc.). It should also cover any payments that are made to the owner of the forest for the right to harvest the timber. These are commonly referred to as stumpage prices. The value of the ecosystem services in this case is not the roadside price after felling, but the stumpage price, equivalent to the residual after deducting the costs of extraction.

6.41. In some cases, this residual may be very small or negative (for example, in the case of abstracted water or open access fishing). Consequently, the implied value of the ecosystem service may very low, zero or negative from an exchange value perspective. A number of different cases can be identified. For example, in the case of water the resource rent is often near zero as there is commonly no competitive market for distributed water and prices are regulated to only cover the costs of supplying water 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 this will reflect the recreational value of the activity.

6.42. Depending on the situation, different valuation approaches may be considered as alternatives to resource rent techniques, for example using replacement costs in the case of water or costs of hunting licenses in the case of recreational hunting (Remme et al., 2014). Most problematic is determining an approach in the case of common pool / open access resources. Note that the benefits produced in these instances (e.g. fish or water) still have market prices, but the ecosystem services are implicitly valued at near zero, implying as well that ecosystem degradation would be valued at zero. Further discussion on potential approaches for accounting in these situations would be welcome.

6.43. Relating ecosystem assets to values for ecosystem services. An important distinction is the one between the valuation of ecosystem services and the valuation of ecosystem assets (and the related issue of valuing ecosystem degradation). Within ecosystem accounting, the valuation of ecosystem assets reflects the overall value of a given spatial area and is estimated by aggregating the net present value of all relevant ecosystem services. These issues are discussed in Chapter 7.

6.44. In pricing theory, the capital costs associated with the supply of ecosystem services, i.e. the cost of any ecosystem degradation, should influence the price set for the outputs. Many approaches to valuation however, implicitly assume that the use of the associated ecosystem asset is sustainable, thus setting these capital costs to zero. The need to incorporate the effect of degradation on the prices of ecosystem services is recognised as a challenge (see Bateman, et al. 2011) but it has not yet been 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, i.e. where the growing and harvesting of the outputs from these activities is not sold on markets but directly consumed by households. A broad range of products may be relevant here including all types of non-timber forest products. Following the conceptual scope of the SNA, the production associated with this activity 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. The handbook on the measurement of the non-observed economy (OECD et al., 2002) provides guidance on measurement approaches in this area. For ecosystem service valuation, the value of the associated ecosystem services can be based on these estimated market prices using techniques noted above for similar provisioning services such as unit resource rents and production functions.

6.46. Valuation of intermediate services. The focus of valuation in the SEEA EEA, and in the majority of other studies, is on final ecosystem services. This focus supports understanding 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, it may imply that those ecosystem 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 and this area of measurement remains one for further research and testing. More generally, the description and measurement of ecological production functions would be an important pathway in understanding the connections between ecosystems.

6.47. Valuation of regulating services. For most provisioning services, there is a connection to market values of benefits that can provide a base for measurement. This is also true for some – but by no means all - cultural services (such as those relating to economic activity in tourism and recreation). However, in the area of regulating services such connections to marketed benefits are unusual. Indeed, for regulating services it can be difficult to appropriately define and measure the actual physical flow of the service because often the service is simply part of ongoing ecosystem processes rather than a function of direct human activity – for example, air filtration and carbon sequestration. The challenge of valuation may thus lie primarily in articulating the link between the services and human activity such that the application of valuation techniques can be well-founded.

6.48. The measurement of non-use values. An important part of the value of ecosystems from a societal perspective can lie in the non-use values that, in principle, are captured in various cultural services provided by ecosystem assets. These values 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). At this point, there are relatively few studies in this area of valuation from the perspective of ecosystem services although the discussion of this area of valuation is a particular focus within the IPBES program of work.[31] From an ecosystem accounting perspective, there is a further open question of the extent to which non-use values can be captured using an exchange value concept even if the associated ecosystem services may be considered within scope.

6.49. The valuation of ecosystem assets with respect to land. In estimating the value of ecosystem assets at exchange values, one important consideration is the value of land that is commonly traded in markets – including, for example, agricultural land. Depending on the circumstance, values of land will incorporate the value of some ecosystem services. However, they are unlikely to capture the value of all of the ecosystem services particularly those that are of a public good nature. Further, market based land values will incorporate elements of value that are not dependent on ecosystems, such as the prospects for property development or the capitalisation of farm subsidies. Consequently, when considering the integration of ecosystem asset valuations into existing national accounts balance sheets, some adjustments will be required to ensure there is no double counting or gaps in valuation for the estimation of total net wealth.

6.50. The valuation of biodiversity and resilience. Biodiversity and resilience are considered in SEEA EEA primarily as characteristics of ecosystem assets and not as ecosystem services. Consequently, they are not separately valued using the general approach outlined here and the relative contribution of biodiversity and resilience is unlikely to be identifiable. Further consideration on how these aspects of ecosystem assets may be incorporated into valuations is required, including in terms of how these characteristics feature in the description of ecological production functions.

6.51. Channels of ecosystem services. Underlying many of these challenges in valuation have been differences of view in the conception of value and its application. As noted earlier, one source of this difference has been the different perspectives of non-market valuation from accountants and economists. Through the ongoing World Bank valuation research seeking to better understand and bridge these differences, a potential way forward has emerged after identifying a valuation framing widely understood in environmental economics but not known to accountants. This framing considers valuation in terms of different channels between the environment and business, individuals and society. Freeman (2013) identifies three main channels:

[31] See https://www.ipbes.net/system/tdf/downloads/IPBES-4-INF-13_EN.pdf?file=1&type=node&id=13413

inputs to production, inputs to household consumption[32] and inputs to well-being[33]. In short:

- Channel #1 – Inputs to production: These are ecosystem services that are used as inputs to economic production. Among many examples these include water regulation and water purification services which are inputs to those economic (producing) units which need a supply of clean water as an input alongside other factors of production. Importantly, this channel is not limited to the valuation of provisioning services since a range of regulating and cultural services will provide inputs to production.
- Channel #2 – Inputs to household consumption: These are ecosystem services that can act as joint inputs to household consumption.[34] That is, there is use of ecosystem services in combination with (or as a substitute for) expenditure on produced goods and services in providing a "product" for consumption. In such cases, ecosystem services and the market goods/services are complementary (or substitute) inputs, and because of this, expenditure on the latter provides a guide to the value placed on the former. Examples include the contribution of ecosystems to recreation and tourism, which are combined with human inputs (e.g. in the form of hotels, restaurants, walking paths) to produce recreation benefits. An example where an ecosystem service is a substitute for market expenditure is air purification services which can substitute for the purchase of a produced good which filters the air.[35]
- Channel #3 – Inputs to well-being: These are ecosystem services that can be inputs which directly contribute to household wellbeing. That is, there is no existing economic production or household consumption where these services first act as inputs. These services are consumed directly in generating benefits: that is, directly from nature without any other (produced) inputs. Examples here are, by their nature, rather abstract and less tangible, but include those services which are valued for reasons of what is usually termed 'non-use' or 'passive-use'.

6.52. All of these channels are well understood in the environmental economic literature on categorizing ecosystem services for valuation purposes. As distinct from an externality based framing for valuation as commonly applied in environmental economics, this "channels" based approach seems to provide a much more direct parallel to the way in which national accountants seek to frame the valuation question. Indeed, the different channels can be seen as equivalent conceptually to different cells within a supply and use account which each record a distinct link between supplier (in this case the ecosystem asset) and user (in this case the different economic units).

6.53. The key conclusion that is emerging from this line of thinking is that the choice of valuation technique will not be purely dependent on the type of ecosystem service – which has been the most observed approach to date. In addition, the choice of valuation technique must also consider the characteristics of the user. In many cases this may not

[32] Strictly speaking, this channel is often referred to as household production. That is, the production of output consumed by a given household, through a combination of inputs from ecosystem services and expenditure on a market good (or goods).

[33] That is, the flow of some ecosystem service contributes directly to household wellbeing rather than via its contribution to economic production or household consumption.

[34] Typically, in environmental economics this is referred to as "household production" We refer to "consumption" here as it is the conventional terminology in accounting.

[35] Firms may also undertake these sort of defensive expenditures: that is, purchase substitute goods to defend against an environmental burden, which exists in the absence of some ecosystem service. The value of this service then might be approximated by estimating how the cost of producing current output changes as a result of a small change in its provisions. Given that this refers to the production side of the economy, this is a pathway under Channel #1 rather than Channel #2, which is defined here as referring to household consumption.

make a significant difference to the choices that have been made, but it does provide a valuation context that is more satisfactory from a national accounting perspective.

6.54. The research into the use of framing valuation in terms of channels is ongoing and at this stage is not elaborated further in these Technical Recommendations. It is noted here to encourage ecosystem accounting compilers to continue to engage with the environmental economics valuation community to find means by which the challenge of valuing ecosystem services can be advanced.

6.5 Recommendations on the valuation of ecosystem services

6.55. There remains a substantial amount of work to be conducted to advance valuation in the context of ecosystem accounting. At one level, there is a need to continue the discussion about the role of valuation both in general terms and with respect to accounting. The main challenge is to provide the appropriate context for the discussion since commonly there are many misunderstandings of the relevant issues. A key issue is understanding that there are different purposes for valuation and there may be some questions that are not best considered using information in monetary terms.

6.56. At a second level, there is a need for understanding and explaining the concept of exchange values for accounting purposes and the development, or adjustment of, valuation techniques to support the estimation of this valuation concept. A possible path forward on this is to distinguish better between the relevant valuation techniques as to: (i) when the ecosystem services can be relatively easily linked to existing market prices and (ii) when the ecosystem services relate to public goods. These two principal targets for valuation involve different challenges.

6.57. One of the most important challenges in accounting is to ensure that the users of the accounts understand the valuation concepts applied in the accounts. Specifically, they should understand that the accounts do not provide an estimate of ‘the value of nature’ or even ‘the economic value of ecosystems’. Instead, the monetary ecosystem accounts estimate 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 valuation of these services is possible.

6.58. Where ecosystem services can be relatively easily linked to market prices (e.g. provisioning services and tourism related services), an important part of the information required for valuing the service may already be in the national accounts. For these services, valuation serves to specify the contribution of the ecosystem to the related benefits already included in the national accounts in monetary terms. Following Table 8.1, for such services a resource rent-based valuation approach may be appropriate, noting potential challenges described above concerning the estimation of low or negative resource rents. The SNA (EC et al, 2009) and the OECD Measuring Capital manual (OECD, 2009) provide detailed guidance on how intermediate inputs, labour and fixed capital should be costed, including for example 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 that is in the national accounts generally involves spatial allocation. In some cases, this is straightforward, as in the case of forests providing timber to a logging company. In other cases, some modelling of spatial interactions between ecosystem users and the ecosystem asset is required, as in the case of allocating the resource rent generated in the tourism sector to (natural) ecosystems.

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 ecosystem services involved provide the basis for valuation. Significant uncertainty may pertain to both the physical models (as discussed in Chapter 5) and the unit values for the ecosystem services. Different regulating services require different valuation methods. Replacement costs methods can be applied, based on the least-cost alternative, if it can reasonably be assumed that the service would indeed be replaced if lost. This method is relevant, for instance, for the flood protection service of coastal or riparian ecosystems in densely populated areas. In case it cannot be assumed that the service would be replaced, an avoided damage cost method may be appropriate (see Table 8.1). Hedonic pricing is another valuation method with which there is ample experience. It can be used to value for example the cultural service underpinning the positive amenity that people obtain from nature, as in the case of eliciting the incremental value of houses with a view or close to green space.

6.61. Other valuation methods have as yet been less frequently applied, but offer the potential to broaden the pallet of valuation methods available for SEEA EEA. For instance, the Simulated Exchange Value approach and the Travel Cost Method can be used to reveal demand curves which would allow a more comprehensive inclusion of tourism and recreation in the ecosystem accounts. Well-functioning Payment Schemes for Ecosystem Services may indicate partial market equilibrium demand and supply for ecosystem services, and associated market prices, but it needs to be examined under what conditions the prices paid for ecosystem services in a PES truly reflect exchange values.

6.62. In general, there is a need for further efforts to estimate exchange values of ecosystem services in practice, for a basket of ecosystem services, across a range of ecosystem types. There are some examples of work heading in this direction (see for example Remme et al., 2014; Sumarga and Hein, 2014) but more testing is required. For some techniques (hedonic pricing, replacement costs, avoided damage costs) there is ample experience in the environmental economics literature that can be built upon. in other cases, e.g. simulated exchange values and the use of the travel cost method and prices from PES schemes in the context of accounting, there is a need for further research before such valuation approaches can become more standardized.

7 Accounting for the value and capacity of ecosystem assets

Key points in this chapter

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 exchange value concepts developed in Chapter 6. This 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 (NPV) of the expected future flows of all ecosystem services generated by an ecosystem asset. This requires an understanding of the likely pattern for the supply and use of each ecosystem service and recognition that the pattern of supply among different ecosystem services from a single ecosystem asset is likely to be correlated.

The estimation of net present value also requires the selection of a discount rate and this choice can have an important impact on the resulting valuations.

A key aspect in understanding the pattern of future flows of ecosystem services is the connection to the condition of the ecosystem asset. This connection between services and condition is reflected in the concept of ecosystem capacity. Ecosystem capacity can be measured in both physical and monetary terms.

The measurement of ecosystem capacity also links to the measurement of ecosystem degradation, i.e. the decline in the condition of ecosystem assets as a result of economic and other human activity.

Further testing and research is required in many areas related to measuring the monetary value and capacity of ecosystem assets including the application of NPV techniques for ecosystem assets, estimating 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 this chapter, and the associated discussion of integration with economic accounts in Chapter 8, is directly linked to the way in which national accountants make the connection to ecosystem information. It is also directly related to the literature on wealth accounting (UNU-IHDP and UNEP, 2014; Hamilton and Clemens, 1999) as it concerns the valuation of natural capital. Given this perspective, some initiatives in ecosystem accounting see that accounting for ecosystem assets in monetary terms is the underlying rationale for measurement in this area (see for example accounting work in the context of the English Natural Capital Committee). The discussion in the SEEA EEA and in these Technical Recommendations is designed to recognise this is not the only perspective that can be taken.

7.2. Underpinning accounting for ecosystem assets in monetary terms is the idea that the monetary value of ecosystem assets can be estimated in the same way as for other assets, i.e. in terms of the future flow of income attributable to an asset. Conceptually, this is true for the value of all economic assets. For most economic assets, this value is estimated for SNA purposes on the basis of recording 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, such as occurs for ecosystem assets, the SNA proposes alternative valuation techniques including the use of the discounted flows of future income (see SEEA EEA Section 5.4 for a summary). This chapter discusses the approaches and challenges in undertaking this aspect of ecosystem accounting.

7.3. The standard logic for accounting for ecosystem assets in monetary terms is to (i) identify the basket of ecosystem services that an ecosystem asset supplies, (ii) estimate the expected ecosystem service flows, i.e. 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, (iii) apply appropriate prices to each flow of ecosystem services and discount each flow to the current time period. This discounted value of future flows represents the net present value of ecosystem assets. This approach follows standard capital accounting theory (see OECD, 2009), and recognises a direct connection between the valuation of ecosystem services and ecosystem assets.

7.4. The expected ecosystem service flows (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, the estimation of ecosystem asset values at any point in time should not assume sustainable use. To do this would imply that ecosystem assets cannot be the subject of ecosystem degradation. At the same time, it may be of considerable interest to understand the difference between expected ecosystem service flows and the level of flows that would be sustainable, i.e. the level that would imply no loss in ecosystem condition in the future. This links directly to the concept of ecosystem capacity. Given the importance of these topics, this chapter discusses at some length the concepts and measurement of ecosystem capacity and ecosystem degradation, with a general conclusion that more discussion and investigation is required to reach a more common understanding of these issues.

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 and additions and reductions in those stocks. Estimates of ecosystem assets in monetary terms are useful for making decisions about alternative uses of ecosystem assets since they provide a consistent basis for comparison. In addition, estimates in monetary terms can be integrated with valuations for 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 the EAA) may point to unsustainable ecosystem use.

7.6. The relevant accounting structure for the ecosystem monetary asset account is shown in Table 7.1. The entries in the rows have been simplified to very basic asset account entries. If more detail is required to account for changes in assets, particularly those related to provisioning services, then additional entries following the structure of the monetary asset account in the SEEA Central Framework (Table 5.3) can be incorporated. These additional entries include growth and normal losses of stock, catastrophic losses (e.g. changes due to natural disasters), upward and downward reappraisals and reclassifications. A separate entry is used to record changes between the opening and closing values of ecosystem assets that are due to revaluations – i.e. changes in the value that are due solely to changes in prices rather than changes in volumes.[36]

7.7. In the columns, different presentations are possible given that the data are 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 (as shown below).

[36] Note that following SEEA Central Framework 5.61, a change in the quality of an ecosystem asset, e.g. due 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 inter-tidal 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 assets																
Additions to stock																
Reductions in stock																
Revaluations																
Closing stock of ecosystem assets																

7.8. The total value of ecosystem assets for a country will be able to be incorporated into extended national balance sheets, as discussed in Chapter 8. Chapter 8 also contains an extended discussion on other aspects of the integration of ecosystem accounts based data into the standard national accounts, for example in the derivation of degradation adjusted measures of national income and the compilation of extended input-output tables.

7.9. Entries in the ecosystem monetary asset account go beyond the measurement requirements of the ecosystem services supply and use account in monetary terms by incorporating the use of net present value (NPV) techniques and assumptions about 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 typically depends upon both the condition of the ecosystem, the 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 (i) the standing stock of timber at a given moment; (ii) the expected (re)growth of the timber stock, which, in turn, is a function of ecosystem condition indicators such as soil fertility; and (iii) expected demand for timber products.

7.11. Assuming that the net present value for each type of service is separable, it is possible to consider the total value and changes in value for each ecosystem service flow separately. This assumption may be considered a significant one in light of the complexities and linkages in the supply of ecosystem services. From an accounting standpoint, the effect of this assumption will depend on the extent to which the factors affecting the future supply of services and the associated asset lives that underpin the net present value calculations are considered in an integrated and coherent manner. If these variables are estimated for each service independently, then it is likely that the separability assumption will be problematic. However, if the potential linkages between services are considered then the concern should be reduced.

7.12. For example, if estimates of carbon sequestration services are made assuming that a forest can sequester carbon over an infinite timeframe, while for the same ecosystem asset, estimated rates of timber provisioning are made assuming the forest is depleted within a limited time frame with no regeneration (e.g. 30 years), 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 and should therefore be applied in estimation of all expected ecosystem service flows.

7.13. For provisioning services, such as timber extraction, accounting for the additions and reductions is conceptually straightforward. In this case, the value of provisioning services will reflect a resource rent (taking into account the estimation challenges noted in Chapter 6). Therefore, accounting for the changing value of provisioning services is equivalent to the advice provided in the SEEA Central Framework and the SNA on accounting for individual environmental assets. Applying this 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. For regulating services, the issue is that the supply of the service does not only depend upon the extent and condition of the ecosystem, but also upon other factors that will not be stable over time. For example, air filtration is a function of the extent and type of vegetation and its leaf area index, but it is also influenced by expected air pollution levels and these can be spatially and temporally heterogeneous. Thus, the higher the concentration of atmospheric particulate matter, the higher 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, with each of them providing only limited information on the capacity of the ecosystem to supply the service over time. Relevant indicators may therefore reflect ecosystem characteristics, such as leaf area index per BSU in the case of air filtration, or they may reflect outputs of the ecosystem, for instance, the amount of water made available for irrigation throughout the year in the case of the water regulating service provided by forests. Establishing accounting entries for changes in ecosystem asset values related to regulating services is therefore not straightforward.

7.16. For cultural services, it may also be challenging to find appropriate physical data for quantifying the services in terms of the underlying ecosystem assets. Cultural services can involve a passive interaction (enjoying without visiting through information obtained from various media) or active interaction (actual visitation) with an ecosystem. Thus, describing the link 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 natural park may physically allow access to a large number of people, but, at some point, the recreational experience gained per individual will decline because of overcrowding.

7.17. Overall, policy-relevant physical indicators about ecosystem assets can be defined for most provisioning services, while indicators for regulating services are more complicated to define but are an active area of research and testing. Indicators for cultural services require the most further development at this stage. It will be appropriate to consider the selection and measurement of these indicators in combination with the development of indicators of condition.

7.18. In a fully spatial approach where sufficient data are available, it is possible to map ecosystem asset values and, where time series are available, 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 using a table such as Table 7.2. This table shows individual ecosystem services in the rows and the relevant aggregate value for each service. Where possible, the accounts could be extended and values attributed to ET. Further, where price effects can be distinctly observed it may be appropriate to identify the revaluation component of the total change in value thus providing a real measure of change in ecosystem asset values.

7.20. Generally, the opening and closing values refer to values at the beginning and end of an accounting year, but 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 services		
Biomass accumulation		
- Timber		
- Crops		
- Grass / fodder		
- Fish		
Water abstraction		
Regulating services		
Carbon sequestration		
Water regulation		
Water purification		
Air filtration		
Nutrient/waste remediation		
Pest & 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. As noted above, the valuation of ecosystem assets, and the estimation of associated changes in the value of ecosystem assets, requires the derivation of net present values for the flows of ecosystem services.[37] Setting aside the issues discussed in other chapters on the measurement of the flows of ecosystem services in physical terms (chapter 5) and the estimation of relevant values for ecosystem services (chapter 6); there remain other measurement considerations in estimating NPV. The SEEA Central Framework section 5.4, provides a comprehensive discussion of the application of NPV for natural resources in an accounting context and readers are referred to that text for a more detailed discussion. A summary of that material and some additional considerations in the context of ecosystem assets in monetary terms are presented here.

[37] A closely related measurement approach is the use of Land Expectations Values commonly used in forest land valuations. This literature will be considered in future research.

7.22. First, it is necessary to understand the expected asset life of the ecosystem. That is, an understanding is required of the length of time that ecosystem services will be supplied into the future. As noted above, this should not be done independently for each ecosystem service. In many cases, the supply of regulating and cultural services will be competing relative to the supply of provisioning services. In these circumstances, it is likely that the estimated asset life for provisioning services provides the relevant upper bound for the asset life assumption. Where an ecosystem asset is being used sustainably, i.e. with no expected decline in ecosystem condition, the asset life appropriate at the current estimation date will be 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.

7.23. In the derivation of macro-level estimates of national wealth, it is common for a generic asset life to be assumed (e.g. 25 years) rather than estimating asset lives that take into account the balance of ecosystem condition and expected service flows. (See for example World Bank, 2011.) Clearly this is more straightforward methodologically. It may also be rationalised at an aggregate level since where discount rates of greater than 5% are used, the contribution of future income flows beyond 30 years to the total asset value diminishes to around 20% (at 5% discount rates) and to around 6% (at 10% discount rates) (See Table A5.1 in SEEA Central Framework Annex A5.2). That is, at higher discount rates much of the value of ecosystem assets will be 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 estimation for a variety of asset life and discount rate alternatives to assess and convey the sensitivity of ecosystem asset values to these choices.

7.24. A priori, there is no preferable generic asset life since it will depend 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 investigation be undertaken into specific asset lives, at least for different ecosystem types. Such work will provide a more robust estimate of the asset lives, and the process will also serve as a form of data confrontation in terms of expectations concerning 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 describing the expected future flows of ecosystem services. This flow may be affected by many considerations, in particular ecosystem condition. It may be useful to separately consider future flows in physical terms and future changes in values of those ecosystem services. A common assumption in national accounting for natural resources is to assume that the resource rent per tonne extracted (unit resource rent) stays constant over the remaining asset life. However, this should only be considered a default basis for estimation, and it would be considerably better if an assessment of possible future trade-offs between different services was undertaken.

7.26. Keeping in mind that the ambition is to provide the best estimate of expected flows, even when assuming the unit resource rent (or more broadly the value per unit of ecosystem services) stays constant into the future, it is possible that the past time series of unit resource rents shows a degree of volatility. In such cases it is recommended that an average of recent periods (say 3-5 years) is used as the basis for estimating future flows. Note that where changes in unit resource rent occur that may be attributed to structural change (e.g. due to changed regulations) then averaging over time periods may not be appropriate. Generally, it should be clear that the requirement to use expectations to determine asset values means these values are less reliable. It is also observed, that the framing for establishing values based on expectations can also be applied to establish values based on alternative future scenarios (i.e. scenarios that may not be the most likely).

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

7.28. Third, as mentioned above, a discount rate is required. The choice of discount rate is an area of much discussion. Economists are by no means clear on what discount rates might be appropriate and there are a number of factors to take into consideration. SEEA Central Framework Annex A5.2 provides a useful summary but also highlights the lack of clarity in advice from experts in this area. Perhaps the key issue for ecosystem accounting is clearly articulating the purpose of valuation and hence the intended valuation concept. Where integration with existing national accounts estimates of income and assets is required, then an exchange value concept is appropriate. Consistent with this choice, the use of a market based discount rate is then appropriate.

7.29. However, where a societal based valuation is required, then other considerations are relevant, in particular assumptions about the relative social importance of different ecosystem services. There may also be interest in identifying the extent to which certain aspects of ecosystem are substitutable along the lines of defining critical natural capital (Ekins, 2003). 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 has a focus on expected flows, the task of selecting a discount rate likely moves outside of the remit of a national statistical office. That said, it must be accepted that there is an underpinning set of assumptions and norms that are implicit in a decision to use market based discount rates.

7.30. Given the range of different 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 to 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 asset life, it is necessary to use a discount rate in real terms, i.e. after adjusting for inflation. Conversely, where the future path of ecosystem services unit values is directly estimated and included in the calculations, then a nominal discount rate should be used. When adjusting a discount rate for inflation (i.e. converting it to real terms), since the essence of a discount rate is to reflect the time value of money, an appropriate measure of inflation is likely one that is economy wide in scope, such as the GDP deflator.

7.32. Fourth, in the estimation of net present values it is usual for a number 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, where regulations change such that the use of an ecosystem asset changes, estimates of NPV prior to the change should be based on the earlier set of regulations and should not be revised on the basis of the changed situation. The change in value associated with the change in circumstance (e.g. 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. The SEEA EEA describes three main ecosystem asset concepts: ecosystem extent, ecosystem condition and expected ecosystem service flows. Ecosystem capacity was recognised to be central to making the connection between ecosystem assets and ecosystem services in accounting terms, but the nature of this connection was not articulated in SEEA EEA. This was for two reasons:

- First, there was recognition 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. Notions of threshold effects, resilience, ecosystem dynamics and other non-linear factors are important to consider.
- Second, since the concept of ecosystem capacity was considered to relate to the overall ecosystem asset, a requirement in measuring capacity was defining an expected basket of ecosystem services. Discussion on how such a basket should be defined was not conclusive.

7.34. Since the release of SEEA EEA in 2013, it has become increasingly apparent that the concept of ecosystem capacity is a central one for explaining the ecosystem accounting model and applying the model in practice. This is especially the case in relation to developing information sets that can support the discussion of sustainability. It is thus clear that further research to capture the key aspects of ecosystem capacity and how they interrelate is needed, together with practical examples. This section provides an initial discussion of this topic utilising material from recent research in Hein et al. (2016).

7.35. An initial definition of ecosystem capacity for accounting purposes is – 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 et al., 2016).

7.36. In the context of developing this definition, the following key points have emerged. A longer discussion of the relevant issues is provided in Hein et al. (2016). That paper also discusses issues in applying the concept of capacity to the different types of ecosystem services, i.e. provisioning, regulating and cultural services and a number of real-world examples are provided in which capacity is assessed. It is noted that ecosystem capacity is being discussed in this later chapter of the Technical Recommendations because it involves the joint discussion of ecosystem condition and ecosystem services and measurement, noting that its measurement is relevant in both biophysical and monetary terms.

7.37. Key recent insights concerning ecosystem capacity are:

i. First, capacity needs to be analysed for specific ecosystem services. The capacity of a forest to supply wood will be different from its capacity to capture air pollutants or sequester carbon. Capacity will have a different connotation for the three types of services provisioning, regulating and cultural.

ii. Second, 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 its ability to supply individual services as a flow over time. In general terms, capacity involves estimating the sustainable use level of ecosystems, in the sense that there is sufficient regeneration (growth less natural losses) of the ecosystem to offset the use of the ecosystem by economic units.

iii. Third, using one ecosystem service can reduce the ecosystem's capacity to supply other ecosystem services. For instance, harvesting wood may reduce opportunities for nature-based tourism in a forest. Capacity, therefore, needs to be assessed in the context of the actual use of the ecosystem, e.g. by considering the carbon sequestration of a forest in the context of actual rates of timber harvesting in a forest. It will also be relevant to consider competing uses of ecosystems when considering the future flows of ecosystem services.

iv. Fourth, capacity is a measure that should relate to both the supply and use of ecosystem services. Analysing capacity therefore requires understanding demand for the services that an ecosystem asset generates. If there is no demand for a service, the ability of an ecosystem to generate that service is not relevant for assessing ecosystem capacity. This could be the case, for example, for a flood control service provided in an area without people. Hence, capacity is akin to sustainable use levels conditional on there being a demand for the services involved.

v. Fifth, the definition of capacity is generally appropriate at more aggregated scales, in particular at the landscape scale and above. If capacity is assessed over too small an area, signals regarding changes in capacity may be misleading because natural fluctuations or ecosystem use will more strongly influence the ecosystem's state relative to when larger areas are assessed (Hein et al., 2016). For example, timber harvesting generally takes place in rotation periods, and 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. Thus, capacity 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. This has been labelled potential ecosystem service supply (e.g. Bagstad et al., 2014; Hein et al., 2016). It may also differ from the basket of ecosystem services that would be obtained under optimal ecosystem management, which could be labelled 'the capability of an ecosystem to supply services' (Hein et al., 2016). Both potential supply and capability are relevant concepts for ecosystem management but 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 where high levels of use of the ecosystem asset take place, 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. This set of circumstances would reflect ecosystem degradation.

7.40. Considering the above, capacity may be monetised on the basis of the NPV of the sustainable flow of ecosystem services. A choice may need to be made in case there are trade-offs between services. For example, sustainable timber logging may not compatible with providing maximum recreational opportunities or air filtration services from the ecosystem. For accounting purposes, the basis for this choice should be the actual or revealed patterns of use and any associated legal and 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, recreation) should be made with the same logging rates in mind, rather than estimating capacity for each service based on alternative patterns of use. At the same time, more consideration is required as to how this may apply in practice. One consideration for example, may be that the unit values of ecosystem services estimated with respect to actual use are not equivalent to those that would apply in the context of sustainable use.

7.41. Even without this consideration, note 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 will have a major influence on the different valuations.

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

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

7.44. For further details on analysing capacity the reader may refer to Hein et al. (2016). A case study has also been undertaken with regard to nitrogen retention services in Europe (La Notte, et al., 2017). Based on these recent insights, further discussions on how capacity can be integrated in the SEEA EEA are required.

7.3.2 Linking ecosystem capacity and ecosystem degradation

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

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

7.47. Both approaches (expected flows and capacity) to measuring degradation result in different metrics, since as noted above, the NPV of expected use will be different from the NPV of capacity (unless the ecosystem is sustainably used). Likewise, annual changes in the NPV of actual use and NPV of capacity will generally be different (even though the direction of change will often be related).

7.48. Reflecting this discussion, there are several approaches to measuring degradation:

i. in physical terms through changes in ecosystem condition indicators

ii. in monetary terms through changes in the NPV of the expected use of ecosystems

iii. in monetary terms through changes in NPV of capacity.

iv. through changes in the NPV of the potential supply – however this may require attributing monetary values (i.e. option values) to potential ecosystem services, i.e. when there is no expected corresponding use.

v. in principle, degradation could also be related to changes in the NPV of capability, i.e. of optimal use of an ecosystem, provided that such an optimal use pattern could be defined.

7.49. However, for any given ecosystem asset there may be several different ways to estimate potential supply and capability involving different use patterns. Thus, these 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 or to the NPV of capacity, or whether both approaches should be considered simultaneously. It is noted that both approaches to measuring degradation have specific policy interpretations. Changes in the NPV of expected use reflect impacts on the economy. Changes in the NPV of capacity reflect changes in the window of opportunities for this and future generations to manage ecosystems sustainably.

7.51. Separately from the examining degradation in the context of the NPV of ecosystem assets, another angle for consideration is that ecosystem degradation occurs when actual ecosystem service flows (in particular, provisioning services) exceed the ecosystem’s capacity to supply that service. Therefore, where 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 to analyse whether flows of ecosystem services in specific areas can be sustained in the future (see Schröter et al., 2014).

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

7.53. There have been proposals to develop accounts for ecosystem capacity. At this stage, an ecosystem capacity account has not been defined. Instead, the emphasis is placed on the measurement of ecosystem capacity for individual services such that there can be 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 can be compiled in the same format as the ecosystem monetary asset account based on individual services (see Table 7.2), with the difference that the values recorded 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 to compile most other ecosystem accounts. Indeed, the compilation of these various accounts (extent, condition, ecosystem services supply and use) will be important in providing the measurement experience and detail for the refinement of 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 role. It represents 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 arise for other reasons. In particular, reductions in asset value due to unforeseen events, that are not part of the use of the asset in production (e.g. due to natural disasters), are not considered part of degradation for accounting purposes. These reductions are treated as a distinct entry – "other changes in volume" - and contribute to explaining the overall change in the value of assets over an accounting period. Further, it is possible that the value of an asset changes solely due to changes in prices. These are considered revaluations for accounting purposes and are also separately recorded.

7.56. These distinctions between accounting entries are reflected in Table 7.3 where the series of entries between opening and closing stock are characterised for different types of assets. Note that for ecosystem assets, depletion will be a subset of degradation, in that 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 will encompass capital costs associated with provisioning services and other ecosystem services. An important aspect in the table is that there is a consistency of treatment in the accounting framework between consumption of fixed capital (depreciation of produced assets), depletion and degradation.

Table 7.3: Accounting entries for depletion and degradation

<table>
<tr><th></th><th colspan="5">Accounting entry</th></tr>
<tr><th>Type of asset</th><th>Opening stock</th><th>Transactions</th><th>Other changes in volume</th><th>Revaluations</th><th>Closing stock</th></tr>
<tr><td>Produced assets</td><td></td><td>Gross fixed capital formation (investment)
Depreciation</td><td rowspan="3">Primarily physical appearance and disappearance of assets
- discoveries
- catastrophic losses
- reappraisals of stock</td><td rowspan="3">Changes in value between opening and closing stock solely due to changes in prices of assets</td><td></td></tr>
<tr><td>Natural resources</td><td></td><td>Depletion</td><td></td></tr>
<tr><td>Ecosystem assets</td><td></td><td>Degradation</td><td></td></tr>
</table>

7.57. However, within this accounting construct, further consideration of exactly how ecosystem degradation should be defined is required, building on the discussion in the previous section concerning the measurement of ecosystem capacity and some additional considerations described in SEEA EEA Chapter 4, namely:

- the treatment of complete changes (conversions) in the use of an ecosystem asset– for example from a forest area to an agricultural area;

- the treatment of situations where economic activity, including household consumption, has an indirect and potentially delayed impact on ecosystem condition – for example, the impacts arising from human-induced climate change;
- the 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. One of the most longstanding challenges in developing fully integrated environmental-economic accounts is the allocation of ecosystem degradation. The SEEA Central Framework proposes a means by which the depletion of natural resources can be incorporated within the standard sequence of accounts of the SNA. This treatment recognises 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 broader concept of degradation have been suggested. Perhaps the most obvious is that the degradation should be attributed to the economic unit that caused the degradation, presuming that this can be determined. Determining the relevant economic unit may be difficult due to distance (i.e. impacts are felt in neighbouring ecosystems) and time (i.e. when the impacts become evident after the activity occurred). Due to both of these factors, the relevant economic unit (i.e. the unit who should be shown 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 complex, since physical degradation of an ecosystem is likely to impact on the supply of multiple ecosystem services that are received by different users.

7.60. These factors are all quite different from the estimation of depreciation (or consumption of fixed capital) for produced assets. Depreciation can be directly attributed 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 conceptual definition of degradation is clear, there remain practical measurement challenges and choices that requiring further discussion and research.

7.4.3 On the use of the restoration cost approach to value ecosystem degradation

7.61. A commonly discussed alternative approach to valuing ecosystem degradation, i.e. other than in relation to the change in the NPV of ecosystem assets, is the use of estimated restoration (and maintenance) costs. Such approaches were initially suggested in the original 1993 SEEA (UN, 1993). Under this approach, an estimate is made of the expenditure that would be required (i.e. not actual expenditures) to restore an ecosystem to its condition at the beginning of the accounting period. This line of thinking is sometimes extended to consider that the accumulated, unpaid restoration costs represent a liability – an ecological debt (Weber, 2011). Note that if the estimated restoration costs had in fact been made, then it is assumed that there would be no recorded decline in condition, i.e. there would be no degradation.

7.62. In the environmental economic community (see for example, Barbier, 2013), restoration cost approaches are not preferred on the basis that they do not reflect the change in the value of the associated services due to the loss of condition and that they are not revealed (i.e. actually paid) costs. In accounting terms, recent work observes that restoration costs are not equivalent to what is undertaken in estimating depreciation, or consumption of fixed capital (Obst and Vardon, 2014; Obst et al., 2015). That is, in estimating consumption of fixed capital the term replacement or restoration cost relates to the expenditure required to replace an asset in its depreciated condition, not to return the asset to an "as new" condition. Finally, it is 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 the accounting framework.

7.63. An alternative approach in the use of estimated restoration costs in the valuation of ecosystem degradation may be to examine 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) may be an indicator of the cost of a decline in condition between those two points in time. Another angle may be to consider not the cost of restoring an ecosystem to an earlier condition but rather the cost, including time, of "building" the ecosystem from a zero base to its currently observed condition. This could be considered conceptually equivalent to the concept of replacement cost in the context of measuring consumption of fixed capital just noted. The change in total restoration cost between two points in time may be an alternative 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 the basket of services and hence provide an estimated value of the ecosystem services for accounting purposes. This logic is akin to the standard approach in national accounts for the estimation of government services such as health and education which are measured at cost. This conceptual issue is somewhat different from the challenge of measuring ecosystem degradation but is not unrelated. It is clear that further discussion on the appropriate accounting interpretation of estimated restoration costs is required.

7.65. Notwithstanding these 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 these costs can provide a sense of economic scale to a discussion of ecosystem degradation, especially where the discussion revolves around the resources required to maintain condition (e.g. where government set upfront charges or bonds in relation to business use of ecosystem assets or associated spatial areas such as mining sites). It may also be analytically useful to compare the estimated restoration costs with the actual expenditures on ecosystem maintenance. When these costs and expenditures are tracked against actual changes in ecosystem condition, some useful information for policy purposes seems likely to emerge.

7.5 Recommendations for compiling ecosystem monetary asset accounts

7.66. To date, there have only been a few examples of the development of ecosystem monetary asset accounts. Pilot testing of the ecosystem monetary asset account was conducted in the Philippines WAVES case study conducted in Palawan (Government of the Philippines and World Bank, 2016). Hence, recommendations in this regard should be seen as preliminary awaiting the accumulation of further experience.

7.67. In principle, the ecosystem monetary asset account should reflect all final ecosystem services supplied by the EAs in the EAA. However, in practice a selection will often be made based on policy priorities and data availability. The basis for the selection, and the consequences in terms of values analysed should be clearly described for the user of the account. SEEA EEA Section 3.5 provides advice on relevant criteria for selecting ecosystem services for measurement.

7.68. In estimating ecosystem asset values, crucial assumptions pertain to the selection of the discount rate and the asset life, as well as to assumptions made regarding use patterns of ecosystems (which should reflect current uses unless there are clear indications of forthcoming changes in use patterns). In selecting the discount rate and the asset life, a guiding principle is that where the purpose is integrating or comparing asset values with those obtained from the SNA, e.g. in compiling national wealth accounts, the compiler of the ecosystem accounts should seek alignment with assumptions made in the national accounts.

7.6 Key issues for research

7.69. Overall, the important need in this area is further piloting and testing of the compilation of ecosystem monetary asset accounts and ecosystem capacity. Within these activities specific areas for research 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, how and when constant unit values for ecosystem services can be assumed in the calculation of NPVs
- Testing the analysis of capacity for different ecosystem types in different social and environmental contexts, see Hein et al. (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, the advice here is that the measurement of ecosystem capacity should be considered to be a topic of ongoing research but with a very high priority. The principle aims in the short term should be (i) to reach a common understanding of the definition of ecosystem capacity and its relationship to other similar concepts; and (ii) to articulate the role of ecosystem capacity within the accounting system, primarily with respect to defining ecosystem degradation.

7.71. To support this research into ecosystem capacity, it would be beneficial for those countries and agencies undertaking testing of ecosystem accounting to consider questions relating to the links between flows of ecosystem services and measures of ecosystem condition. These links should, in any event, be a part of any 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, will involve the use of information on ecosystem condition.

8 Integrating ecosystem accounting information with standard national accounts

Key points in this chapter

Full integration of ecosystem accounting information with the standard national accounts comprises a number of steps and, from a national accounting perspective may be considered the end point of measurement by integrating information on ecosystem extent, ecosystem condition and ecosystem services in physical and monetary terms.

There are four broad types of integration: combined presentations, extended supply and use accounts, institutional sector accounts and balance sheets. Each of these types of integration provides information suited to answering different policy and analytical questions.

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 to 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 form extended economic production functions.

Institutional sector accounts provide the means by which standard aggregates of income and production can be adjusted for ecosystem degradation – i.e. 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 only incorporate values related to provisioning services.

Aside from combined presentations, the other types of integration require ecosystem data to be estimated in monetary terms. Thus, the measurement challenges outlined in chapters 6 and 7 apply, especially concerning the application of net present value techniques in the measurement of ecosystem assets and the measurement of ecosystem degradation.

There are other approaches to the integration of ecosystem and economic data, including wealth accounting and full cost accounting. These have a similar intent to the SEEA based approaches but apply some different measurement concepts and boundaries.

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 the SEEA. This reflects that the SEEA has been developed as a system that extends and complements the standard economic accounts of the SNA. Indeed, for some, the prime ambition of developing the SEEA is deriving adjusted measures of national income and economic activity that take into account environmental information, for example in the form of depletion or degradation adjusted measures of GDP.

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

8.3. As a result, while a theoretical framework for integrated accounting of ecosystems and economic activity is largely in place, its implementation represents the end point of a series of compilation steps (described in section 8.2) and also requires a range of assumptions on the nature of the required valuation and integration. Compilers should recognise that some of these accounting matters remain the subject of ongoing discussion.

8.4. While the ambition to complete a full integration of ecosystem accounting information remains, it is important to recognise that there are various means by which ecosystem accounting data can be combined with economic data. Section 8.3 describes the use of combined presentations that are valuable in this context.

8.5. This chapter builds on the discussion provided in SEEA EEA Chapter 6 and summarises some of the key points in integrating ecosystem accounting data with standard economic data.

8.2 Steps required for full integration with the national accounts

8.6. Historically, the approach to integrating ecosystem related information with the national accounts has moved directly to the question of the valuation of degradation and the appropriate recording and allocation of degradation in the accounts. This is characteristic of the different approaches outlined by national accountants (see for example, Harrison, 1993 and Vanoli, 1995). However, the question of exactly how the integration should be undertaken was never fully resolved.

8.7. Significantly, as explained in SEEA EEA and also in recent literature (e.g. Edens and Hein, 2013; Obst et al, 2015) the emergence of the concept of ecosystem services has allowed a reconceptualization of the integration with the national accounts. It is this new basis for integration that is inherent in the SEEA EEA and is discussed here.

8.8. Utilizing the concept of ecosystem services, the following (generalised) steps toward full integration emerge. The precise ordering of these steps will vary in practice, and iteration between the steps is to be expected. Of particular note is that where the intent of an ecosystem accounting project is to focus primarily on the measurement of the value of ecosystem assets, it may be most appropriate to commence at step five and incorporate information from earlier steps only as required.

i. Delineate the relevant spatial areas to create mutually exclusive ecosystem assets

ii. Identify and measure the supply of ecosystem services from each ecosystem type or asset and determine the relevant users

iii. Measure the condition of each ecosystem asset

iv. Assess the future flows of ecosystem services from each ecosystem asset based on consideration of the current condition and capacity of ecosystem assets

v. Estimate the monetary value of all ecosystem services

vi. 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

vii. Estimate the change in net present value over an accounting period and determine the monetary value of ecosystem degradation

viii. 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 this list, which itself is somewhat stylised, that the full integration of ecosystem accounting information into the standard national accounts (step viii) is not straightforward. At the same time, maintaining a longer-term objective of integration gives a clear purpose and rationale for the selection and structuring of the ecosystem information that is required in the earlier steps. Further, the information organised in the early steps will be of direct usefulness for decision making and monitoring in its own right. Consequently, while the objective of full integration may be challenging, it plays an important part in providing direction for ecosystem accounting.

8.10. A significant challenge in working through these steps is the requirement for aggregation across ecosystem services and ecosystem assets. Aggregation requires a range of assumptions about the relationships between different ecosystem services and different ecosystem assets. In particular, there is often an implicit assumption that separate estimates for different services and assets can be summed. The reality is that such a summation will tend to abstract, to some degree, from the inherent complexity of the underlying ecosystem functions and processes. (In the same way as the national accounts is an abstraction of the underlying economic system.) The question for compilers and analysts is whether the degree of abstraction that is represented in ecosystem accounts is appropriate in terms of making better informed decisions on the use and management of ecosystems.

8.3 Combined presentations

8.11. An immediate means of combining the information from ecosystem accounting with the standard national accounts is the use of combined presentations. Combined presentations are described in the SEEA Central Framework Chapter 6. In essence, they are tables that support the presentation of information from a variety of sources in a manner that facilitates comparison between economic and environmental data. This is achieved by use of common classifications and accounting principles.

8.12. Two examples with respect to ecosystem accounting are (i) the provision of information for specific ecosystem assets on changes in condition combined with information on the expenditure on environmental protection on those assets; and (ii) information on the flows of ecosystem services generated by an ecosystem asset combined with information on economic activity associated with that asset. Examples in this second case would be showing data on flows of ecosystem services from a forest alongside data on employment in the forestry industry or comparison of agriculture related ecosystem services to agricultural value added. Such comparisons may give an insight into the relative significance of ecosystem service flows to various beneficiaries.

8.13. Another type of information for inclusion in combined presentations that may support decision making is data on potential restoration costs and actual expenditures on the maintenance and restoration of ecosystem assets. Information on restoration costs is likely to be of particular relevance in the management of ecosystems and in understanding the degree of investment in ecosystems that might be needed to maintain or improve condition.

8.14. Over time, as information is gathered on the actual expenditure on restoring ecosystem assets, this may be complemented with information on flows of ecosystem services, and a more complete picture of the relationships between ecosystem condition and ecosystem services should emerge. Indeed, one of the key roles of the ecosystem accounting model is to facilitate the organisation of information of this type and thus support more detailed analysis in the future.

8.15. SEEA EEA Chapter 6 provides some additional comments in relation to combined presentations. The key point is that there is considerable flexibility in the design of combined presentations. While they do not represent a full integration of information in accounting terms, they may support a more informed discussion of the relationship between ecosystems and economic activity in a manner that takes into account spatial and environmental context. Further, they may help underpin 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 (SUA) represent the first accounts in which explicit consideration must be given to the boundaries between the current economic measures and measures of ecosystem services in terms of the structure of the accounts. The ambition in the augmented SUA is to present the information on the supply and use of ecosystem services as extensions to the standard SNA SUA.

8.17. Building on the discussion in Chapter 4 concerning ecosystem services supply and use accounts, and as reflected in Table 4.4, there are two key aspects to this extension. First, recalling that the ecosystem accounting model implies an extension to the standard production boundary, the set of products within scope of the SUA is broader and hence the size of the SUA must increase. This can be done through the addition of new rows (representing the ecosystem services).

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

8.19. Conceptually, it is possible to extend the SUA further to also incorporate intermediate ecosystem services. For example, where pollination services are relevant an additional row might be added to recognise these flows as inputs to the generation of final ecosystem services. However, the general recommendation is that the extension of SUA should be limited to final ecosystem services. In part, this reflects that if intermediate services were also to be added then the complexity of the table would be increased. However, it is also that from an economy wide production perspective, any recorded intermediate services would net out in accounting terms and their effect is embodied in the final ecosystem services. The analysis of intermediate services, and hence flows between ecosystems, may be better analysed using data in the basic ecosystem services SUA in chapter 5.

8.20. The second key aspect of the extended SUA is that additional columns are required to take into account the production of ecosystem services – i.e. the ecosystem assets are considered additional producing units alongside the current set of establishments classified by industry (agriculture, manufacturing, etc.). Given that SUA are generally compiled at 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 this case, the detail would be covered in the ecosystem services supply and use account. However, there may be interest in adding columns for certain ET (ensuring aggregation to national level) or by specific EAA within a country (e.g. for specific water catchments, protected areas or sub-national jurisdictions).

8.21. A related extension is environmentally-extended input-output tables (EE-IOT). These tables are regularly compiled, including at regional and world levels, for the analysis of embodied GHG emissions, water and similar environmental flows and also to support analysis of interlinkages and spill-over effects of policies and shocks on the economic system. An introduction to EE-IOT is contained in SEEA Applications and Extensions Chapter 3 (UN et al., 2017).

8.22. For EE-IOT, information on environmental flows (e.g. GHG emissions by industry) is appended to the standard input-output table and then matrix algebra is used to integrate the data for analytical purposes. What is required is that the information on environmental flows is classified and structured in the same manner as for the standard input-output data. The additional information may be in physical or monetary form even while the standard input-output data remain in monetary form. Thus, using EE-IOT techniques, it is possible to analyse selected ecosystem services without developing a full extended SUA.

8.23. However, for EE-IOT it is not necessary to make any changes to the standard SNA production boundary. For the extended SUA envisioned here, the ecosystem services are fully integrated within the standard SUA reflecting the extension of the production boundary. This is an important development.

8.24. An important result of integrating the flows of ecosystem services in extended SUA is that it is clear how the commonly discussed topic of "double counting" is 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 those final ecosystem services that contribute to SNA benefits are included. The stylised presentation in Table 8.1 demonstrates that double counting is 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 manner in which double counting is dealt with for accounting purposes.

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

8.26. Part B extends this 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. Note that the overall value added is unchanged (at 80 currency units) even though total supply has increased due to the inclusion of the production of ecosystem services. This 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, i.e. SNA benefits. The increase in value added from production is also reflected in increased final demand of households.

Table 8.1: Example of integration of final ecosystem services with current national accounts estimates

	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	45	20	30		95

Source: Obst et al, 2015

8.5 Integrated sequence of institutional sector accounts

8.28. As discussed, for certain purposes it may also be relevant to integrate ecosystem information into the broader sequence of institutional sector accounts and balance sheets of the SNA. The general logic and structure of the sequence of accounts is described in detail in the SNA and is summarised in the SEEA Central Framework, Chapter 6. The focus in these accounts moves away from information on production and consumption and instead focuses on 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 between incomes, investment and balance sheets and, in this context, 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 this integration is shown in Table 8.2, taken directly from SEEA EEA Annex A6. Table 8.2 presents simplified versions of two models (A and B). 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 the 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, the table above 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 the previous example (table 8.1), in models A and B, the rise in GDP occurs in relation only to the final consumption of ecosystem services that relate to non-SNA benefits, i.e. the air filtration services of 30 units. This final consumption is also attributed to households and leads to a final measure of GDP (gross value added) in models A and B of 230. In Model A, the GDP is allocated between the value added of the farmer (120) and the value added of the ecosystem asset (110). In Model B, all of the value added is attributed to the farmer 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 GDP, these measures can now be adjusted for the cost of capital in the derivation of that GDP. This includes the deduction of depreciation (consumption of fixed capital) of produced assets, depletion of natural resources and ecosystem degradation. In the SNA, only depreciation is deducted to provide a measurement of net domestic product (NDP). Deduction of all costs of capital provides a measure termed degradation adjusted NDP. In Table 8.2, total deprecation is 10 units and ecosystem degradation is 15 units.

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

8.35. In the Technical Recommendations, no explicit recommendation between Model A and B is provided. Discussion on other issues in ecosystem accounting suggests treating ecosystem assets as distinct producing units fits neatly with logic of measurement in other parts of the ecosystem accounting framework, particularly on recording the supply of ecosystem services.

8.36. The significant implication of recognising ecosystem assets as a distinct sector is that all ecosystem degradation is deducted from the value of the ecosystem services generated by those assets. That is, the degradation is allocated to the ecosystem assets as the producing units in the model. Thus, as shown in table 8.2 for Model A degradation adjusted value added for ecosystems is 95 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
Int. consumption – Products	0		0	0	0		0
Int. 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 adj. Net Operating Surplus	**60**		**95**	**155**	**155**		**155**
Allocation and use of income accounts							
Degradation adj. 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 – Eco. serv.		30		30		30	30
Degradation adjusted net saving	**140**	**-150**	**-15**	**-25**	**125**	**-150**	**-25**

Source: SEEA EEA Table A6.1 (UN et al., 2014b)

8.37. This issue is resolved, at least in principle, in Model B since it does not introduce an additional sector for ecosystem assets and rather 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 for applying Model B in practice lies in the extent to which individual ecosystem assets can be attributed to individual economic units and sectors. This may be clear where a unit is a direct user of specific ecosystem services but where there is the supply of public services (e.g. water regulation) from private land holdings complete allocation of an asset (and its value) to a single institutional sector may not be appropriate.

8.39. To explain this from a full accounting system approach, in this example, by allocating all of the ecosystem asset to the farmer it could imply that the full value of the ecosystem asset 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. This may not provide a suitable recording for the allocation of assets on the balance sheet.

8.40. The issue to be resolved is the balance between the allocation of the costs of degradation to an appropriate economic unit and the attribution of the value of ecosystem assets to the economic unit to the appropriate user of the services. The same accounting challenge was confronted in the allocation of depletion of mineral and energy resources in the SEEA Central Framework. The resolution in that case was to show a series of transfers such that 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 this recording has not been developed at this stage.

8.41. It is noted that the approach to the allocation of degradation in some cases may be relatively straightforward. However, in many other cases, the nature of the impacts of economic activity on the environment are complex. For example, the impacts may occur in areas well away from the source of the impact, may occur in time periods well after the impact occurred, or may be unknown to the relevant units. In addition, it is not necessarily clear in what way the loss of benefits incurred by the impacted sectors should be related to the income of the sector causing the impact. These matters have been debated at length in the national accounting community without any clear resolution. Thus, while an appropriate accounting treatment can be determined, the application of a treatment in practice and a recommendation on a preferred approach will require further discussion of the appropriate treatments in a range of cases where economic and human activity leads to degradation of ecosystem assets.

8.42. The final section of table 8.2 concerns the allocation and use of income accounts. The aim of these accounts is to provide a measure of saving for the economy as a whole and for each sector. For Model A, this requires recording an adjustment titled "ecosystem transfers" that reflects that the farmer and the household sector need resources to purchase ecosystem services from the ecosystem assets. Recording these transfers allows the saving of the three sectors in Model A to reflect the actual cash positions, recognising that flows of depreciation or degradation do not affect the cash position.

8.43. In Model B, these ecosystem transfers are not required since there is no stand-alone ecosystem sector. The difference in net saving for farmers between Model A and Model B simply reflects that in Model B the ecosystem degradation of 15 units is allocated to the farmer thus reducing the net saving to 125 units.

8.6 Extended and integrated balance sheets

8.44. The second type of integrated accounts are balance sheets, in which 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 in 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 would seem a relatively straightforward step. However, for a variety of reasons, it is likely to be quite complex. There are two main challenges that are described at more length in SEEA EEA Chapter

6. First, in a full SNA and SEEA Central Framework balance sheet, there will already be values recorded for natural resources, such as timber and fish. Since the value of these resources is embedded in the value of ecosystem assets, via the valuation of provisioning services, it will be necessary to appropriately ensure the value of natural resources is not double counted. This issue will also apply to various cultivated biological resources, such as orchards and vineyards.

8.46. Second, in many countries, the value of land will be recorded on the SNA balance sheet 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 some extent. However, they are unlikely to capture a full basket of ecosystem services, particularly those that have clear public good characteristics and longer-term benefits. Also, the land value may well reflect aspects that are not ecosystem services in nature – for example, the location and the value of alternative uses (e.g. for urban development). Adjusting market values of land for these considerations will require careful consideration.

8.47. In comparing the values of ecosystem assets with values currently incorporated into SNA balance sheets, it is important to recognise the different underlying scopes of environmental assets. In broad terms, the SNA balance sheets will have lower values for environmental assets as a result of the SEEA EEA including the values of additional ecosystem services. At the same time, the SEEA EEA values of ecosystem assets do not cover all environmental assets – most notably sub-soil mineral and energy resources[38]. The effects of these two differences on the total value of environmental assets will vary from country to country.

8.48. A final challenge in the area of integrating the accounts arises when applying the accounting approach at the level of an individual ecosystem asset. Recall that the valuation of an ecosystem asset is directly related to the basket of final ecosystem services that are expected to be generated from an asset. At the level of individual ecosystem assets however, there will be cases where an asset supplies few, or no, final ecosystem services (for example, a high mountain forest) but, instead plays a supporting role in supplying intermediate services to neighbouring ecosystems. In this 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 this 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 sub-national scales. Resolution of this issue requires the incorporation of intermediate services into the ecosystem accounting model in an explicit manner and associated work to record 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 to motivate the development of other parts of the ecosystem accounting framework. At the same time, it is clear that: (i) work is needed to progress the development of the ecosystem accounts which must underpin the integrated accounts described here; and (ii) that further research and testing is 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. There is tremendous value in these accounts in their own right.

[38] Accounting for these environmental assets is described in the SEEA Central Framework.

8.7 Alternative approaches to integration

8.50. The sections above describe integration with the institutional sector accounts and balance sheets following standard SNA measurement definitions and boundaries. This is a natural objective for the SEEA and will be important when seeking to use data already published in the national accounts, for example on national wealth and saving, 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 provide alternative approaches to the integration of ecosystem and economic data. Three alternative integrated approaches are summarised here.

8.51. A well-developed approach, usually referred to as wealth accounting, has developed as a branch of economics since the mid-1970s. Wealth accounting seeks to aggregate the value of all relevant assets/capitals including produced, natural, human and social capital. The most prominent work has been completed by the World Bank (2011) and by UNU-IHDP and UNEP (2014). Their methods vary in the detail but they are broadly similar approaches.

8.52. In concept, wealth accounting aims to value each form of capital in terms of its marginal contribution to human welfare (Dasgupta, 2009; Arrow et al., 2012). By doing so shadow prices are estimated for each asset type. From a national accounting perspective while a focus on marginal prices is appropriate, estimation of the contribution to welfare is different from a focus on exchange value.

8.53. Given the purpose of wealth accounting, the conceptual approach to integration is quite appropriate. However, in practice, often values for produced assets from the standard national accounts based on exchange values are combined with valuations for other capitals based on welfare valuation concepts. Hence, there may be a lack of alignment between the valuation approaches for different capitals. For natural capital, it is clear that the use of exchange values for ecosystem services would not correspond directly to the conceptual requirements of wealth accounting, although there will be strong connections between the two approaches.

8.54. A second approach to integration builds on the use of restoration costs as a measure of ecosystem degradation and records corresponding ecological liabilities on the national balance sheet. That is, unpaid restoration costs that arise when an ecosystem declines in condition are treated as a liability. This approach is described as a possible extension in the ENCA QSP (Weber, 2014a) and has also been suggested for use at the corporate level by the UK Natural Capital Committee. From a national accounting perspective, there are a number of difficulties with this approach:

- First, there is the question of whether restoration costs are a suitable estimate of ecosystem degradation, as discussed in chapter 7.
- Second, there is a question of when liabilities should be recognised. If there is no expectation that the restoration will take place then, at least for accounting purposes, no liability should be recognised. In effect, recognising these liabilities is in the first instance a social or analytical choice rather than an application of accounting principles.
- Third, if a liability is recognised then, all else being equal, net wealth should fall by that amount. However, since the recognition of the liability reflects the degradation of an asset there will be both a fall in an asset and an increase in a liability for the same event. This implies a double counting on the balance sheet in terms of the impact on net wealth. This issue does not arise in the integrated accounting approach described earlier in this chapter since the only balance sheet change is the fall in the asset value due to degradation. An alternative

solution to the double counting issue would be to record the liability but keep the ecosystem asset value unchanged but this seems counter-intuitive.

8.55. Overall, while recording ecological debts seems attractive 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 integrating approach described here is that of full cost accounting. This is an accounting approach that has developed in corporate accounting. The intent behind full cost accounting is to estimate and record the broader costs of a company's impacts on the environment as part of their ongoing operating costs thus resulting in an adjusted profit and loss statement. For example, the costs of GHG 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 can be noted. First, the approach largely excludes consideration of ecosystem services in terms of recognising ecosystem services as inputs to the production process. Hence, within 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 the capital base of a company and hence no impact on the company's balance sheet or recording of ecosystem degradation as a capital cost. It would be implicitly included in the adjusted profit and loss statement to the extent that this degradation was part of the derivation of costs associated with the specific impacts assessed, but this would not be a specific focus.

8.59. Third, the incorporation of costs associated with residual flows (emissions, pollutants, etc.) is not something 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 these costs can be part of a measure of ecosystem degradation. Further work is required to understand the links between the valuation of externalities and ecosystem accounting, recognising that the 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. From a national accounting perspective, the 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 represents an important aspect of the SEEA. While recognising the need for additional discussion, particularly on the allocation of degradation, the adoption of ecosystem accounting has demonstrated that a full integration is conceptually possible.

8.62. At the same time, there are numerous challenges in measurement that must be worked through. These particularly concern the aggregation of stocks and flows across ecosystem services and ecosystem assets. These are important challenges to be confronted through testing and on-going research. This chapter has described some specific issues concerning integration but the measurement issues raised in other chapters are equally relevant in working towards a complete integrated accounting dataset.

8.63. While work continues on developing these full links between ecosystem and economic data, there are other options that can be pursued. Combined presentations, as described in SEEA EEA Chapter 6 and in this chapter, 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 this area is likely to be considerably supported by a focus on presenting data at meaningful spatial level.

8.64. As work within a country proceeds on ecosystem accounting, it is important that any related or similar work on the integration of environmental and economic data is placed in context. Generally, it is not a question of data being in competition, but rather it is a case of different data being suited for specific purposes. Explaining the link between different measurement approaches and different policy questions is an important role for national statisticians.

9 Thematic accounts

Key points in this chapter

Thematic accounts are standalone accounts on topics of interest in their own right and also of direct relevance in the measurement of ecosystems and in assessing policy responses.

The thematic accounts described in this chapter cover accounts for land, carbon, water and species-level biodiversity and reflect the discussion of these accounts in the SEEA Central Framework (for land and water) and in the SEEA EEA (for carbon and species-level biodiversity).

Land accounts can focus on land use, land cover and land ownership. The development of land accounts 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. Working at this level will require the use of hydrological models but this work 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 co-ordinating information on carbon and complements measurement within the Inter-governmental Panel on Climate Change (IPCC) framework and the 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. In accounting terms, this permits recognition of declines or improvements in biodiversity over time and links to the capacity of ecosystems to supply ecosystem services.

In all cases - 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 these data and methods within the SEEA EEA framework.

9.1 Introduction

9.1. The ecosystem accounts described in earlier chapters provide a coherent coverage of information pertaining to ecosystem assets and ecosystem services. At the same time, from both an analytical and a measurement perspective, it can be challenging to focus only on a systems perspective. More commonly, our view of ecosystems, and our policy responses, are framed using themes that concern specific aspects of the economy–environment relationship. Four themes that are consistently evident are land, water, carbon and biodiversity. This chapter summarises accounting in relation to these themes reflecting the more detailed discussion of accounting for these themes in the SEEA Central Framework and the SEEA EEA.

9.2. The incorporation of a thematic focus in the context of ecosystem accounting provides two benefits. First, it enables a closer link to be drawn between the compilation of ecosystem accounts and the likely areas of policy response – for example in terms of land management, management of catchments, carbon emissions policy and maintenance of protected areas.

9.3. Second, the data that are used to understand trends in thematic areas can also be used to compile ecosystem accounts. This can be seen from two perspectives, first from the practical perspective that entries in the ecosystem accounts can be sourced from thematic accounts (e.g. estimates of water provisioning services from water accounts); and second, recognising that a number of the thematic accounts can be considered to each measure distinct ecological functions or cycles – i.e. the carbon cycle the hydrological cycle, etc. In this sense, the thematic accounts provide a different but comprehensive information to support ecosystem accounting.

9.4. It is relevant to note that while measurement in each of the four main themes is relatively well advanced, the work on the SEEA has highlighted the potential to use accounting approaches to (i) improve the co-ordination of data and (ii) recognise links between the themes.

9.5. In the case of two themes – land and water – the SEEA Central Framework and the SEEA Water provide the conceptual grounding for accounting. For carbon, as a single element, it is actually quite well suited as a subject for accounting. It has thus been relatively straightforward to consider adapting the measurement of carbon into a broad accounting structure. The relevant concepts are described in the SEEA EEA. For biodiversity, the application of accounting principles continues to develop. SEEA EEA section 4.5 introduced relevant ideas for accounting for biodiversity but further work has taken place reflected in a report completed by UNEP-WCMC (2016) and further testing continues.

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 and use the information presented in these thematic accounts to support discussion of environmental-economic issues. In particular, information from the thematic accounts, when presented in the context of ecosystem condition and services measures, can provide a more tangible hook for users when making links between ecosystems and policy choices.

9.7. This chapter provides a summary of the relevant accounting issues for each of these four areas and, in section 9.6, other potential thematic accounts are described.

9.2 Accounting for land

9.2.1 Introduction

9.8. Following the accounting principles and structures described in the SEEA Central Framework, accounting for land, particularly land cover, will be 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 compilation of a variety of accounts utilising different classifications of land including land use/management, land cover, and land ownership. In applying these classifications, links to standard SNA classifications of industry (ISIC) and institutional sector. Land accounting incorporates standard asset account structures and also change matrices and tables that cross-classify areas of land, for example land cover cross classified with land ownership (by institutional sector). These various aspects of land accounting are covered in the SEEA Central Framework Chapter 5.

9.9. Ecosystem extent accounts, described in Technical Recommendations chapter 3, are a specific account recording the area and change in area of different ecosystem types (ET). The classification used for ecosystem extent accounting should reflect aspects of both land use and land cover and hence generally an extent account will be similar in structure to land accounts from the SEEA Central Framework but will differ in the types of areas being accounted for. At an aggregate or initial level, it may be necessary to define classes of ET on the basis of land cover classes. In this case the ecosystem extent accounts and land cover accounts (as described in the SEEA Central Framework) will be equivalent.

9.10. While the detailed ET 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 different ecosystem types at a broad level, to support understanding 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, urbanisation and similar forms of landscape change. As recognised in ecosystem accounting, understanding these types of changes is not sufficient for understanding the effects on ecosystem condition or flows of ecosystem services but it is a relevant starting point.

9.12. As noted above, the total area of a country may also be classified according to land use or land ownership criteria. An interim land use classification is provided in the SEEA Central Framework (Table 5.11 and Annex I). Land ownership 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 will often be a connection between tree-covered areas and forestry. However, it is not possible for a simple integration of land cover and land use classes to be described.

9.13. Information on land use and land ownership will be important in understanding 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 land ownership be compiled following the advice in the SEEA Central Framework. A useful output for ecosystem accounting may be a table which 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 provide an important tool to link environmental and socio-economic data, essentially providing a means by which policy can be placed in a spatial context. A key link here is recognising that implementation of policy to maintain and restore ecosystem condition is likely to require the involvement of land holders. Hence, understanding the connection between land ownership, current use and the relevant ecosystem types can provide the means by which decisions on appropriate policy interventions can be made.

9.15. Generally, the initial focus of land accounting is on terrestrial areas of a country, including freshwater bodies. Within this scope land must be classified into various classes (type of cover, type of use, or type of owning economic unit). Often there will be relevant national classifications and datasets but alignment or correspondence to international classifications is a positive step. Chapter 3 discusses issues of classification in more detail.

9.16. As recognised in chapter 3, and in the SEEA Central Framework, accounting for ecosystem extent and land can be extended to encompass marine and coastal areas. Work on marine and coastal ecosystems in an ecosystem accounting context is developing as referenced in chapter 3 and no further articulation is provided in this chapter.

9.17. The basic structure of a land account follows the structure of an asset account as described in the SEEA Central Framework. That is, there will be 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 due to human activities.

9.18. In addition to an asset account, information on land cover and land use may be organised in the form of properly vetted and quality controlled change matrices which show how, over an accounting period, the composition of land has changed. An example of such a matrix for land cover is provided in the SEEA Central Framework, Table 5.14 (UN et al., 2014a).

9.2.2 *Relevant data and source materials*

9.19. Ivanov (2015) discusses the compilation of land accounts in more detail. In terms of data requirements, that paper distinguishes between dynamic and permanent features. Dynamic features include information on land use, land cover and vegetation type. Permanent features include information on administrative boundaries, ecological regions, and river basins. Combinations of both administrative boundaries and ecological regions, such as Statistics Canada's (2016) Census Metropolitan Area-Ecosystems (CMA-E), can also be developed when appropriate.

9.20. The compilation of accounts will generally require bringing these various data together using GIS systems to produce data for a country as a whole. The ambition in accounting terms is to generate harmonised maps, in time series, such that the stock and changes in stock can be consistently accounted for.

9.21. Materials to support land accounting include the SEEA Central Framework, the SEEA EEA and the ENCA QSP. The ENCA QSP in particular has an extensive discussion of land cover accounting and associated data sources and methods.

9.22. Additional support and guidance is available in looking at country examples and case studies. Relevant examples include the work of the European Environment Agency (Weber, 2011), the ABS (2015), Statistics Canada (2013), the Victorian Department of Sustainability and Environment (2013) and in Mauritius (Weber, 2014b).

9.2.3 *Key issues and challenges in measurement*

9.23. There is a range of measurement challenges in land accounting. An immediate challenge is being able to integrate the various data to produce harmonised geo-databases and, for accounting purposes, measures of change over time. This requires careful consideration of scale and classification in combining different data sets at the same point in time and the same data set at different points in time.

9.24. In general terms, higher levels of detail will be better but will also have higher resource costs. Balancing the resources available with the degree of accuracy required will be important. A relevant issue in this context is understanding approaches to the validation of data, particularly since much data will be derived from remote sensing (earth observation) sources, including satellite imagery. Ideally, some degree of sampled ground truthing must be undertaken or some other quality control and data confrontation process, for example comparison to administrative data, information from agricultural and population census or other sources[39].

9.25. The Land Use and Cover Area Survey (LUCAS) has been developed in recent years by Eurostat following an integrated approach involving sampled reference points to measure land use and land cover across Europe. This approach may provide additional ideas for measurement approaches at national level.

9.26. The approach to classifying land is particularly important for communicating messages on the changing composition of land at national level. For land cover, there is now an ISO standard[40] that underpins the Land Cover Classification System (LCCS version 3) as developed by the FAO (FAO and GLCN, 2009). This provides a structure by which each type of land cover around the world can be consistently classified. It

[39] For example, the FAO has used sampled locations from Google Earth to "ground truth" its satellite based estimates of land cover.

[40] ISO 19144-2:2012 specifies a Land Cover Meta Language (LCML) expressed as a UML metamodel that allows different land cover classification systems to be described based on the physiognomic aspects. http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=44342

thus provides a way of linking the various land cover classifications that are in use in different countries and regions.

9.27. While this provides a base level classification tool, the approaches to the formation of higher level classes that can be used to summarise 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 the SEEA Central Framework. Establishing a broadly accepted set of high level (say 10-15) classes of land cover (and the associated definitions of these classes) would be a significant step forward in coordinating information. It would further underpin greater alignment in ecosystem accounting discussions and applications. At the same time, for analysis of changes over time, a smaller number of classes may be most appropriate to ensure that the measurement of change is as accurate as possible.

9.28. With regard to the classification of land use, the SEEA Central Framework describes an interim land use classification with seven high level classes of land use based on work on agriculture, forestry and fisheries land use by the FAO, and UN Economic Commission for Europe (UNECE) work on the classification of land use for all economic activities. It also introduced classes concerning inland water, coastal waters and marine areas extending to a country's exclusive economic zone (EEZ). The finalisation of classifications for land use and land cover are a priority on the research agenda for the SEEA Central Framework.

9.29. It should be recognised that the use of land cover and land use data reflects the use of two dimensions to represent a three-dimensional world. In the context of multiple class datasets, this can lead to significant trade-offs in measurement of individual classes and potential biases. In particular, differences will likely emerge in comparing the results for a given ecosystem type (e.g. wetlands) from a multiple class land cover datasets and from a single class dataset that is specifically designed to consider that ecosystem type. Where possible, it is recommended that information from single class datasets is 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. In their own right, land accounts provide important information on environmental trends. Also, their compilation requires the organisation of spatial data which in turn provides the inputs for the delineation of spatial units and ecosystem accounting. Finally, a focus on land provides a platform for integrating environmental and socio-economic data.

9.31. A number of relevant areas for testing land accounts are presented in chapter 3 in relation to the delineation of spatial units and the compilation of ecosystem extent accounts. In terms of areas for research, the main issues, beyond those already noted in chapter 3, concern (i) finalising appropriate classifications for land cover and land use beyond the interim classifications of the SEEA Central Framework; and (ii) determining the best approaches to account for linear features, such as rivers, beaches and hedgerows.

9.32. From a practical perspective, testing and additional advice needs to be provided on:

- The interpretation of land cover and use data, particularly in the context of using remote sensing and satellite data.
- Understanding 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 for 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 which may be relatively small in 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 underpins the production of food, fibre and energy in many countries. The management of water, including taking into account cross-boundary flows (e.g. the Nile River), and the joint ownership of surface water bodies (e.g. Lake Victoria), is an important focus for many governments around the world.

9.34. Accounting for stocks and flows of water is a key feature of the SEEA Central Framework, the SEEA Water and the SEEA EEA. Whatever the context, accounting for water resources should be undertaken following the standard advice in the SEEA Central Framework. This short section is intended only to provide direction to relevant technical and compilation materials rather than reproduce or summarise the content of the SEEA manuals.

9.35. Accounting for water is relevant to ecosystem accounting in a number of ways. First, water is a key feature of ecosystems and hence the measurement of the stocks and changes in stocks of water resources is a relevant aspect in the measurement of ecosystem condition. Accounting for changes in water quality would also be an important contribution to ecosystem accounting but this area of water accounting is not well developed from a SEEA perspective.

9.36. Second, there are a number of ecosystem services which relate directly to water. These include the provisioning service of water when it is abstracted for use (irrigation, drinking, hydropower), the regulating 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, the regulation of water flows to provide flood protection benefits and the filtration of water by ecosystem assets.

9.37. Measurements in all of these areas are ultimately important within a complete set of ecosystem accounts. The water resource accounts of the SEEA Central Framework and the SEEA Water focus on two areas – (a) the supply and use of water; and (b) the asset account for water. They provide the basis for accounting for stocks and flows of water. Of particular note is that the accounting can be undertaken at a sub-national level and compilation at catchment level is recommended.

9.38. At the level of individual water catchments or basins, information may be available that provides a characterisation of each catchment, for example using information on temperature, precipitation, population density, nutrient flow, barrier density, fragmentation, etc. Such information will support the compilation and interpretation of ecosystem accounts.

9.3.2 Relevant data and source materials

9.39. There are many relevant materials to support the compilation of water accounts. Aside from the content in the SEEA Central Framework and the SEEA EEA, there is also SEEA Water (UN, 2012b) and the associated International Recommendations on Water Statistics (IRWS) (UN, 2012a). Chapter 6 of the ENCA QSP also describes much relevant information.

9.40. There is a wide range of data sources, including global data sets that might be considered for use in water accounting. Vardon (2014a) provides a good overview and links to these data sources, and also provides a description of some relevant country examples. In some cases, the use of GIS tools will be relevant to estimate water stocks and flows in areas that are not regularly gauged or where observed data are not available. To date, over 50 countries have trialled the development of SEEA based water accounts. Consequently, there is a broad and increasing body of knowledge and experience in water accounting that can be drawn on.

9.3.3 Key issues and challenges in measurement

9.41. There remain some specific challenges in accounting for water, especially in an ecosystem accounting context. Linked to the issue of defining spatial units, there is the need for clarity on the delineation of wetlands with the scale of analysis being a particular area of concern. Many wetlands may be quite small but disproportionately important within larger land cover types (for example, in grasslands).

9.42. To more fully incorporate information pertaining to the hydrological cycle, integrating information on groundwater within the ecosystem accounting framework requires further consideration. To date ecosystem accounting has generally focused on surface water resources. The incorporation of the atmosphere would also be relevant in this context.

9.43. Integration of information on stream flow and water yield will also be appropriate. While these are not standard SEEA accounting entries, indicators on these aspects of the hydrological system will be relevant in understanding the system and more completely assessing ecosystem condition. 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 socio-economic activity.

9.44. Given that flows of water are often key pathways between different ecosystems, more work is needed to understand and account 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 further reflection suggests that incorporating certain intermediate ecosystem services is required.

9.45. A general challenge in water accounting from a national accounts perspective is that national data on stocks and flows of water resources may not be overly meaningful. Instead, standardized information at a catchment level is required. While it may be straightforward to propose measurement at this level of detail, developing estimates at a catchment level will be resource intensive. Further, in some situations, sub-annual (including daily) data may be needed to understand the dynamics of seasonal fluctuations in water supply and water use (see, for example, Statistics Canada, 2010). Such an understanding will be missed if working only with annual data or long-term averages.

9.3.4 Recommended activities and research issues

9.46. The main conclusion in relation to accounting for water resources is that there is a wide array of information and examples of water accounting in practice to support countries that wish to start work in this area. Further, there are many datasets that can provide a starting point for compilation. Testing the compilation of water accounts can therefore be given a very high priority.

9.47. Vardon (2014a) highlighted a number of areas in which further research might be conducted. These include accounting for dependencies between ecosystem assets within catchments (including flows of intermediate ecosystem services), advancing discussion on the valuation of water resources and accounting for water quality at a broad scale. Further, the integration of information on groundwater and atmospheric water would complement 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. Carbon has a central place in ecosystem and other environmental processes and hence accounting for carbon stocks and transfers between them must be seen as an important aspect of environmental-economic accounting. This short section is intended only to provide direction to relevant technical and compilation materials rather than to reproduce or summarise the content of those materials.

9.49. Accounting for carbon in the SEEA commenced in the context of accounting for carbon stored in forests and for GHG emissions. Accounting for these stocks and flows of carbon was included in the SEEA Central Framework. With the development of the 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. Thus, it 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. These issues include the analysis of 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 carbon taxes, its direct measurement is of high relevance.

9.51. In ecosystem accounting, information on stocks and flows of carbon may be used in two main areas. First, it may be considered as a broad indicator in the measurement of ecosystem condition. For example, following Chapin et al. (2006) changes in the net ecosystem carbon balance can be used as an indicator of ecosystem condition. However, it should be recognised that in many contexts, the stock of biomass carbon is generated through human actions (e.g. plantation forests) and consequently measures of the carbon balance will provide poor measures of ecosystem condition if used as a proxy for the degree of naturalness of the ecosystem. The second area of use of carbon accounts in ecosystem accounts relates to 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 SEEA EEA Chapter 4. The compilation of that account, with a focus on biocarbon and geocarbon, involves the collection of (i) data on land vegetation/cover and the rates at which different land/vegetation cover types sequester and store carbon in above and below ground biomass; (ii) data on the carbon content of soils; and (iii) information on sub-soil fossil fuel resources. A summary of relevant data sources and links to those sources is presented in Vardon (2014b). A particularly relevant source is information compiled by countries as part of reporting to the IPCC although not all land types are included under the Kyoto Protocol.

9.53. Advice on the compilation of carbon accounts is summarised in the SEEA EEA. A more detailed explanation is provided by Ajani and Comisari (2014) which describes the development of a carbon account for Australia including discussion of the relevance and application of the account.

9.54. A number of aspects of carbon accounting are also reflected in the SEEA Central Framework. For example, air emission accounts will include flows of GHG emissions; and mineral and energy resource asset accounts will record stocks and changes in stocks of sub-soil fossil fuel resources. Within the SEEA framing, all of the information on these various parts of the carbon cycle should be able to be brought together to provide a coherent picture of carbon stocks and flows for a country. For SEEA EEA purposes, the key distinction is the need to compile carbon accounts at a finer level of spatial detail, e.g. by EA or ET.

9.55. The ENCA QSP provides a detailed discussion on accounting for changes in biocarbon at national scale including a discussion of global datasets and measurement challenges. Of particular relevance, is the work undertaken on the measurement of carbon through the FAO Forest Resource Assessment (FRA) (FAO, 2015) which is conducted every five years. The FRA asks for estimates of carbon stock for forests including above and below ground carbon stocks. These data may provide a useful starting point for compiling a time series of carbon accounts. Further, they may provide a sufficient level of detail by type of forest such that the interpretation of changes in the carbon balance can be better associated to changes in ecosystem condition.

9.4.3 *Key issues and challenges in measurement*

9.56. Compared to other areas of measurement, the measurement issues in relation to carbon have relatively well-researched, reflecting the substantial resources that have been applied to this measurement task within the IPCC processes. Nonetheless, there remain important issues of data quality to consider and challenges exist in using point measurements for estimation of stocks of carbon across large scale areas and in accounting for the wide variety of vegetation and soil types since different carbon content ratios will apply in different situations. Related to these issues, the sourcing of information via either remote sensing or using local sources requires balancing between coverage and accuracy.

9.4.4 *Recommended activities and research issues*

9.57. Given the high policy relevance of carbon and the comparably large resources directed at measuring stocks and flows of carbon at national level, it is recommended that countries support the development of carbon accounts. The preparation of these accounts can provide information on broad trends in environmental change and also provide insight into the requirements of 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 functioning and resilient ecosystems that in turn deliver ecosystem services such as food, the regulation of our climate, aesthetic enjoyment and other cultural benefits.

9.59. The SEEA EEA provides a framework to measure and link ecosystem service flows supported by biodiversity and other characteristics (e.g. soil type, altitude) with the economy and other human activities. It also allows 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 to build an understanding of the relationship between biodiversity and economic activity.

9.60. On the whole, the perspective taken in the SEEA EEA is that biodiversity is a characteristic that is directly relevant in measurement of the condition of ecosystem assets. Measures of biodiversity are considered to relate primarily to ecosystem assets in the accounting model. Thus, potential connections to biodiversity, such as birdwatching or fishing, are considered derivative from biodiversity rather than flows of biodiversity services in their own right. This approach is consistent with a view that biodiversity can be degraded or enhanced over time, an attribute that applies only to assets in an accounting context.

9.61. Further, people may appreciate, and therefore value, specific elements of biodiversity, for example when they take an interest in the conservation of endemic and/or iconic species. This is reflected, for instance, in the creation of protected areas in many countries. These species can only survive in the long-term when the overall condition of the ecosystems in which they occur is maintained, a logic that highlights again the distinction between the measurement of specific ecosystem services, the existence of individual species and ecosystem condition. The discussion of biodiversity in accounting for ecosystem stocks and flows must therefore be undertaken with appropriate care.

9.62. In the framing of the SEEA EEA, species-level biodiversity may be considered as a characteristic of an individual EA or connected EAs (for example, EAs linked via patterns of migration for certain species). Ecosystem-level biodiversity emerges from assessment of the diversity of ET (depending on the suitability of the classification of 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, where people gain benefit from experiencing the diversity of nature (as distinct from services received from appreciation of individual species). In these circumstances, it is relevant to recognise 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. Beyond supporting ecosystem accounting, biodiversity accounting also provides opportunities for the harmonization of national level biodiversity data alongside other reporting mechanisms, such as the CBD through the implementation of National Biodiversity Strategies and Action Plans (NBSAPs) and reporting on the SDGs.

9.65. In order to reflect the multi-layered relation between biodiversity, ecosystem functioning, ecosystem services and the human appreciation of ecosystems, a range of biodiversity indicators should be considered. Species indicators may be selected on the basis of the importance of species for specific ecosystem processes, for being indicative of ecosystem condition or functioning, or because the species represent specific aspects that people appreciate in biodiversity, such as the occurrence or abundance of threatened, endemic and/or iconic species.

9.66. Integrated accounting for aspects of biodiversity is still developing and experimentation on biodiversity accounting by countries is less advanced than for water or carbon accounting. To advance work, a paper was commissioned as part of the ANCA project (UNEP-WCMC, 2015). This led to a follow up workshop and publication, specifically focusing on exploring approaches to accounting for species in the context of the SEEA EEA (UNEP-WCMC, 2016). This section summarizes the findings of these outputs but does not attempt to provide definitive descriptions of biodiversity or its measurement.

9.5.2 Assessing ecosystem-level and species-level biodiversity

9.67. Assessments of biodiversity generally consider ecosystem-level and species-level biodiversity due to the cost and complexity of assessing genetic-level biodiversity. However, genetic-level biodiversity is an important topic and may be integrated into ecosystem accounting in the future.

9.68. Ideally, data should meet the following general criteria to be suitable for accounting for biodiversity. The data should:

- Be accessible at a spatial resolution suitable for accounting. This allows data to be mapped to individual ecosystem assets and types.
- Be temporally relevant. This informs net changes in the stock of biodiversity between the opening and closing of accounting periods.
- Be comparable to a common reference condition. This allows the comparison of biodiversity measures against a benchmark indicative of a balanced state and aids aggregation of different types of biodiversity data.
- Be possible to aggregate the measures to provide a composite indicator of the condition of biodiversity (e.g., via the Simpson Index or aggregation using a common reference condition). The change in this composite indicator between accounting periods provides an indication of the net biodiversity balance.
- Be comparable over space and time. This allows direct comparison of biodiversity stocks in different ecosystem types.

9.69. Ecosystem-level biodiversity may be assessed using information on ecosystem extent as described in Chapter 3. Extent measures are based on data on land cover, land use, habitat and other ecosystem data, commonly sourced from satellite remote sensing. Within the SEEA EEA framework, these data inputs also provide spatial information for delineating ecosystem assets on the basis of common characteristics. Many countries have their own ecosystem classification standards and methods for mapping them, and work is progressing towards an internationally accepted ecosystem classification.

9.70. When accounting for ecosystem-level biodiversity, it may be useful to supplement information within the ecosystem extent account with more detailed information on species, such as vegetation classes, community composition or other characteristics. To best support integration, this work should be undertaken in the context of the spatial areas defined for ecosystem extent accounting rather than for land cover accounts as described in the SEEA Central Framework.

9.71. Given that ecosystem-level biodiversity is captured in the ecosystem extent account, the focus of thematic biodiversity accounting in this chapter is on species-level biodiversity. Ideally, the development of a biodiversity account using species data should move beyond simple counts of the number of species (the species richness) and include the population size of each species (the species abundance) as this provides more information on the status of species.

9.72. The International Union for the Conservation of Nature (IUCN) Red List of Ecosystems (Keith, et al., 2013) will, in due course, meet the criteria listed above by generating measures of ecosystem condition based on risk of ecosystem collapse. The spatial resolution will be high enough for national level ecosystem accounting (anticipated to be at least 250m resolution). 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 5-year basis. The application of the quantitative categories and criteria will ensure consistency and comparability between countries and over time.

9.73. In regard to species-level biodiversity data, three approaches that are relevant to different thematic biodiversity accounting concerns are noted here. First, the IUCN Red List of Threatened Species (IUCN, 2014) which measures extinction risk. Application of the IUCN Red List categories and criteria ensures consistency in assessment over space, over time, and between assessors. While originally designed for global assessments, methods are available to allow disaggregation of the Red List Index to national levels. Downscaling of the global Red List 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 are used to ensure as broad and relevant a coverage as possible.

9.74. Second, the Norwegian Nature Index (NNI) (Certain and Skarpaas, 2011) uses indicators from a variety of species groups and major ecosystem types that measure deviation from a reference state. The NNI produces a single ‘value’ that provides information on the condition of species-level biodiversity (and other characteristics) in ecosystems. The NNI incorporates expert judgment, monitoring-based estimates, and model-based estimates, so the method can be used in both data rich and data poor areas.

9.75. Third, the Living Planet Index (LPI) (WWF, 2014) aggregates species population trend data from different sources and across multiple spatial scales. The methodology involves a series of aggregations in order to avoid bias induced by including only well-known taxonomic groups and well-studied locations. With systematic monitoring of species abundance, the data lends itself to incorporation in an accounting format.

9.76. Species-level biodiversity is challenging to document and describe fully because of the large number of different species and species occurrences, even in relatively species-poor environments. Consequently, ecosystem-level biodiversity or accounting for ecosystem types can provide a useful “coarse-filter surrogate” for species-level biodiversity. If ecosystem-level biodiversity is reasonably well documented through mapping and classifying different ecosystem types, much species-level biodiversity is accounted for when ecosystem-level biodiversity is accounted for. For example, a decline in ecosystem-level biodiversity would likely be accompanied by a decline in species-level biodiversity.

9.77. There are a number of designations for ecologically important places that can support species-level biodiversity measurement. These include Key Biodiversity Areas (KBAs), Alliance for Zero Extinction (AZE) sites, Biodiversity hot-spots identified by Conservation International, national parks and nature reserves. Accounting for the extent of these areas 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 to identify biodiversity-related policy priorities to help determine what information should be compiled, covering plants, animals and to a lesser extent fungi. This step will also establish the required resolution of data (both spatial and temporal) necessary to address these priorities.

9.79. Establishing an inventory of all existing monitoring data will help identify any 'data-gaps'. Identifying data gaps could inform a protocol for further data gathering (e.g., via monitoring or modelling approaches). Countries should also consider their reporting obligations to regional processes and biodiversity-related conventions/agreements, such as the CBD or the Ramsar Convention.

9.80. Developing measures of species-level biodiversity is resource intensive and has methodological challenges. A complete inventory of a country's species is not possible and so the species to be included in an account will need to be prioritized. Some species (e.g. keystone or umbrella species) are better indicators of biodiversity and ecological condition than others. Other species may be of particular relevance for because of their functional roles (e.g., pollinating species), cultural importance (e.g., sacred plants and animals) or conservation concern (e.g., threatened species). When selecting species, the broader the representation of taxonomic groups (e.g. plants, birds, mammals etc.), the better the account will estimate overall biodiversity (see Remme et al., 2016 for details). Instead of focusing purely on individual species, it may also be useful to construct accounts for species groups (e.g., taxonomic, trophic or functional groups).

9.81. Any prioritization exercise should be driven by the intended uses of the biodiversity accounts. More than one species-level biodiversity account may be required in order to answer the range of biodiversity relevant policy questions. For instance, UNEP-WCMC (2016) proposes that prioritized species or species groups be organized in either holistic accounts or in separate accounts of:

a. Species of conservation concern

b. Species important for ecosystem condition and/or functioning

c. Species important for ecosystem service delivery

UNEP-WCMC (2016) identifies that these accounts could be supplemented (or substituted where data is limited) with accounts of Red List Status and / or accounts of the extent of important places (Key Biodiversity Areas, National Parks, etc.).

9.82. When measuring species-level biodiversity, it is important to distinguish between quantity and variation. Considering species-level biodiversity in terms of quantity (e.g., abundance) will be important when accounting for the stock of particular aspects of biodiversity is of interest. However, this does not reflect the emphasis of variability implicit in the CBD's definition of biological diversity (CBD, 1992). When applied to species, this variation is expressed by alpha (within communities), beta (between communities) and gamma (within a landscape) diversity. Therefore, when creating a Species Account, analysts should consult with ecologists to ensure meaningful data is 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 primary direct observation data on biodiversity is the ideal, this is unlikely to be available at the spatial resolution required for ecosystem accounting in most countries. A number of habitat based approaches are available for upscaling or downscaling data on species level biodiversity to estimate species status. These include using preferred habitat or land use modelling, species-area curves and expert judgment approaches. A portfolio of these approaches will be required to inform biodiversity accounting. It is important however, that any application of these approaches is supported by regular updating of primary monitoring data and that as far as possible national level data is used to underpin modelling approaches.

9.5.4 Limitations and issues to resolve

9.84. Accounting tables should be designed to organise information in a way that makes it possible to scale, aggregate and compare with other ecosystem accounting areas. Given the generally heterogeneous nature of species data, and the variation in species assemblages between both ecosystems and locations, this is not easily achievable at present. Reference condition based aggregation approaches may be possible but further research into how measures of status for different species can be meaningfully aggregated across species, ecosystems and geographical domains is required.

9.85. In their present state, the majority of potential global datasets do not provide the temporal or spatial resolution necessary to inform national level biodiversity accounting. Further, developing biodiversity accounts that are globally comparable is likely to be challenging, particularly when relative measures of biodiversity are employed as this requires a consistent reference condition.

9.86. While a single biodiversity indicator may provide an overall indication of ecosystem condition for an ecosystem asset, it is unlikely to be useful in informing the link to ecosystem service supply. This is because there will be different aspects of biodiversity that will be 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 in their own right, (e.g. for their existence or aesthetic enjoyment) information contained within a species-level biodiversity account can inform ecosystem service supply estimates directly.

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. There exist various market and non-market based valuation techniques to generate values for certain aspects of biodiversity (e.g., see TEEB, 2010b). However, this will only be possible for a subset of ecosystem services for which production functions can be described and the marginal value of biodiversity will likely remain implicit in estimated values of various ecosystem services.

9.5.5 Recommendations for testing and further research

9.88. A range of topics can be the focus of testing and further research. First, more testing is required of suitable spatial scales for biodiversity accounting. This should be supported with further testing of modelling and other approaches for generating spatially explicit information on the status of biodiversity via various downscaling and upscaling approaches, building on those approaches explored in UNEP-WCMC (2016). Protocols for validation and calibration of these 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 to aggregate ecosystem and species data and indicators across ecosystem units is required. This should include how indicators of ecosystem-level 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 needs to be considered. Ideally, this should also consider the implications of ecotones (i.e. the areas of high biodiversity on ecosystem borders).

9.90. The biodiversity accounts proposed in the SEEA EEA allow for causes of addition and reduction in the stocks of species-level biodiversity to be recorded. There are obvious benefits to recording such causal relationships. However, completing these entries would require additional data collection and may often be difficult to complete in a balanced manner. The possibilities for undertaking this work would benefit from testing in a specific case study, possibly via linkages to land ownership or land use. At this stage, it is recommended that countries focus on the development of time series of biodiversity reflected as a sequence of opening and closing positions.

9.91. As discussed in this section, biodiversity is considered as a potential indicator of condition in the ecosystem condition account. Ideally, improvements and reductions in condition are also recorded in the condition account. For biodiversity, there exist multiple drivers of biodiversity loss and so a supplementary account for drivers of change in ecosystem condition could be a possibility for testing. This would also provide a suitable structure for capturing factors such as habitat fragmentation and invasive species.

9.92. The link between biodiversity and ecosystem service delivery is complex. There will often be time lags between changes in biodiversity and changes to the supply of ecosystem services. Furthermore, capturing information on the importance of biodiversity to ecosystem functional redundancy and resilience is challenging due to non-linear and threshold effects. Given the importance of biodiversity to ecosystem functioning and sustaining ecosystem service provision, measurement of ecosystem functional redundancy, resilience and thresholds is a key issue to be addressed in the ecosystem accounting framework. Further research is required in this regard.

9.93. Finally, further research is required on the application of information from biodiversity accounts. This should examine the role of these accounts in the context of informing and monitoring policy actions (e.g., progress towards the CBD Aichi Targets and the UN Sustainable Development Goals) and how to integrate them into the wider SEEA EEA framework.

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 will need 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 described in the SEEA Central Framework)
- Fish and other aquatic resources (accounting described in the SEEA Central Framework)
- Other biological resources including livestock, orchards, plantations, wild animals (accounting described in the SEEA Central Framework)
- Soil resources (accounting described in the SEEA Central Framework although further development is required)

- Nutrient flows and balances for nitrogen and phosphorous (accounting described in the SEEA Agriculture, Forestry and Fisheries (FAO, 2016) and in OECD/Eurostat manuals (e.g. Eurostat and OECD, 2013))
- GHG emissions and residual flows (e.g. solid waste, wastewater) (accounting described in the SEEA Central Framework)
- Data on production and use of outputs from agricultural, forestry and fisheries activity (accounting described in the SEEA Agriculture, Forestry and Fisheries (FAO, 2016))
- Data on tourism and recreation (some coverage of accounting in Tourism Satellite Accounts) (UN et al., 2010) and in the developing framework for measuring sustainable tourism (UNWTO, 2017)
- Population data.

9.95. In other contexts, some of these data are considered indicators of "drivers" of changes in ecosystem condition and the supply of ecosystem services. That is, many of these types of data point to the changing extent of human interaction with the environment. Information on drivers is likely to be of particular relevance in (i) understanding changes in condition for specific ecosystems; (ii) developing appropriate assumptions about future flows of ecosystem services; (iii) assessing ecosystem capacity; and (iv) valuing ecosystem assets.

9.96. Particular note is made here on the relevance of accounting for GHG emissions and other residual flows such as solid waste. These flows are not ecosystem services within the ecosystem accounting model but given the potential negative impact of these flows on environmental condition there may be significant interest in how a narrative concerning residual flows may be incorporated into ecosystem accounting. In practice, the most straightforward first step would be presenting information on flows of emissions and residual flows by type of economic unit by spatial area where possible, alongside information on changes in environmental condition for the same and nearby areas. Subsequently, analysis may be able to determine linkages between changes in condition and the residual flows and the associated economic units.

9.97. A more complete integration of residual flows into the ecosystem accounting model would require an understanding of dependencies between ecosystems. In particular, it would require incorporation of the atmosphere as a type of spatial "area", whose condition is affected by economic activity, including for example, forest fires. Where there is a decline in condition then 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 air space for air transport. The extension just described will however, require further consideration.

9.98. It is likely that, in order to generate the data at the appropriate spatial scale for ecosystem accounting, some scaling and modelling of the information covered by the accounts listed above will be required. The issue of scaling is discussed in Bordt (2015b).

9.99. Further, particularly for the measurement of ecosystem services, it will be necessary to use models of ecosystem processes to estimate the relevant flows. These models will require additional data, usually of a scientific and ecological nature. Over time, as the accounts develop, it is likely to be possible to investigate the alignment and consistency between the scientific data and the socio-economic data, particularly as it pertains to specific spatial areas or ecosystems. In this sense, the ecosystem accounting model provides both a rationale and a platform for data integration.

Annex 1: Summary of various Natural Capital Accounting initiatives

Introduction

A1.1 This annex provides a summary of SEEA-based ecosystem accounting projects and initiatives around the world. Many of these projects are at relatively early stages and their inclusion in this summary is intended to provide a sense of both the level of interest that has been generated in ecosystem accounting since its endorsement by UN Statistical Commission in 2013, and of the potential for work to be undertaken in a wide range of countries and contexts.

A1.2 The summary is not intended to be exhaustive, nor does it provide sufficient detail concerning each project to fully understand the progress that has been made or the methods and data that will be or have been used. Nonetheless, for those countries and agencies interested in commencing work on ecosystem accounting it provides a useful introduction.

A1.3 Given the pace of advancement in ecosystem accounting, this summary will not be current for any length of time. Consequently, it is highly recommended that those interested in understanding more detail on SEEA-based ecosystem accounting project check the latest information on the UNSD website – see https://unstats.un.org/unsd/envaccounting/eea_project/default.asp The WAVES Knowledge Center https://www.wavespartnership.org/knowledge-center) is another website with links to relevant ecosystem accounting projects and reports.

Summary of countries and organizations with ecosystem accounting initiatives

A1.4 The following table provides a list of those countries and agencies with SEEA-based ecosystem accounting programs as of December 2017. The listing is based on responses to the UNSD survey on implementation of the SEEA that was completed at the end of October 2017 and on other projects known to members of the SEEA EEA Technical Committee. There is also a lot of research being undertaken in various parts of the academic community, but this work is not in scope of this Annex.

A1.5 As noted above, the list is not intended to be exhaustive, although it does highlight the quite extensive coverage around the world. Further, it should be apparent from the list that many of the initiatives are not led by national statistical offices, but being led by other government agencies, sub-national levels of government, and/or non-government organizations. The common feature of these projects is their use of the SEEA.

A1.6 The list does not attempt to separately identify cases where there are multiple projects underway in the same country. Further, there are a number of countries for which the projects are currently focused on individual regions within a country rather than at a national level. It is also noted that the specific ecosystem accounts that are being undertaken in each project varies, ranging from ecosystem extent and condition accounts to ecosystem services accounts and valuation.

A1.7 Finally, 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 for example those focusing on the development of earth observation data, the measurement of biodiversity and ecosystem condition or the valuation of ecosystem services.

Table A1-1: SEEA EEA based ecosystem accounting activities

Countries with activities at national or sub-national level (lead agencies in brackets)

Australia (ABS, Commonwealth and State Departments of Environment)

Belgium (Inbo, VITO)

Canada (Statistics Canada)

Colombia (National Statistical Office)

Denmark (National Statistical Office)

Finland (SYKE, Statistics Finland)

Indonesia (BPS)

Liberia (Conservation International)

Mauritius (Statistical Office)

Mexico (INEGI)

Netherlands (Statistics Netherlands, University of Wageningen)

Norway (NINA, Statistics Norway)

Peru (Conservation International)

Philippines (PSA, NEDA, DENR)

Rwanda (RNRA, World Bank, SNAPP)

South Africa (Statistics SA, SANBI)

Spain (Institute for Public Goods and Policies (IPP), Consejo Superior de Investigaciones Científicas (CSIC))

Sweden (National Statistical Office)

Uganda (NPA, NEMA, UNEP-WCMC)

United Kingdom (DEFRA, ONS)

USA (USGS, NOAA, US EPA, BEA)

Countries participating in international ecosystem accounting programs

ANCA – UNSD, SCBD & UN Environment (2013-2015; 7 countries)

South Africa, Mexico, Vietnam, Bhutan, Mauritius, Chile, Indonesia

EU KIP-INCA – Eurostat, EU Joint Research Centre, the Directorates-General for Environment and for Research and Innovation of the European Commission, and the European Environment Agency (2015-2020; EU level and several EU Member States)

Natural Capital Accounting and the Valuation of Ecosystem Services project UNSD, UN Environment, funded by the EU (2016-2019; 5 countries)

China, India, Brazil, South Africa, Mexico

WAVES Partnership – World Bank (2010 onwards; 8 countries)

Philippines, Rwanda, Costa Rica, Guatemala, Botswana, Madagascar, Indonesia, Colombia

Selected descriptions of ecosystem accounting activities

Australia

A1.8 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 timeframes. Some recent examples include: the Australian Bureau of Statistics' Experimental Environmental-Economic Accounts for the Great Barrier Reef, 2017[41], which cover both the marine and terrestrial environments of the region, including information on a selection of ecosystem services and natural capital; the Victorian Government has integrated environmental-economic accounting into government reporting, program evaluation and decision-making and has produced the Marine and Coastal Ecosystem Accounts for Port Philip Bay, 2016[42], Valuing Victoria's Parks, 2015[43], and Victorian Experimental Ecosystem Accounts, 2013[44], which all feature ecosystem accounting; the Office of the ACT Commissioner for Sustainability and Environment has developed a pilot set of environmental-economic accounts for the ACT[45] based on the SEEA framework, including ecosystem accounts; and researchers from the Australian National University's Fenner School produced a set of experimental ecosystem accounts for the Central Highlands of Victoria[46] under the National Environmental Science Program, which assessed the use and economic contribution of ecosystem assets from the region and discussed alternative implications for alternative activities.

A1.9 In late 2016, the meeting of 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 5 years was agreed and appropriate resourcing identified, and in 2018 a detailed action plan will be established taking advantage of the substantive advances being made in other countries.

Canada

A1.10 In 2011, Statistics Canada received funding for a three year interdepartmental project titled "Measuring Ecosystem Goods and Services". The purpose of the project was to conduct research into the development of ecosystem accounts, indicators and valuation techniques. The results were released in 2013 in the annual publication Human Activity and the Environment (HAE): Measuring Ecosystem Goods and Services[47]. This work led to increased efforts in ecosystem accounting. For example, in 2016, initial ecosystem account tables were created for Canada's largest metropolitan areas, and published in the HAE report, "The changing landscape of Canadian metropolitan areas"[48]. In 2017, Statistics Canada released asset, supply and use accounts for freshwater, in the HAE report "Freshwater in Canada"[49], 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

[41] http://www.abs.gov.au/ausstats%5Cabs@.nsf/0/021873EB0FFA07A9CA2581820077EE15?Opendocument
[42] https://www.environment.vic.gov.au/__data/assets/pdf_file/0025/49813/Marine-and-Coastal-Ecosystem-Accounting-Port-Phillip-Bay.pdf
[43] https://www.forestsandreserves.vic.gov.au/media-releases/valuing-victorias-parks
[44] https://www.environment.vic.gov.au/__data/assets/pdf_file/0028/49816/Victorian-Experimental-Ecosystem-Accounts,-March-2013.pdf
[45] http://www.environmentcommissioner.act.gov.au/publications/environmental-economic-accounts
[46] https://tsrhub.worldsecuresystems.com/Ecosystem%20Complete%20Report_V5_highest%20quality.pdf
[47] http://www.statcan.gc.ca/pub/16-201-x/2013000/aftertoc-aprestdm1-eng.htm
[48] http://www.statcan.gc.ca/pub/16-201-x/16-201-x2016000-eng.htm
[49] http://www.statcan.gc.ca/pub/16-201-x/2017000/sec-1-eng.htm

cover change, and nutrient residuals and emissions. Work is ongoing to update and augment these accounts on a regular basis.

Indonesia

A1.11 In 2016, Statistics Indonesia started testing the SEEA EEA approach including development of a land account (in collaboration with the Ministry for Environment and Forestry, other government agencies and supported by the World Bank WAVES program) for all regions as well as at the national scale. In 2018, an ecosystem extent account for Sumatera and Kalimantan, and a water account for a major watershed in Java is planned to be released. A pilot account for peat lands is also being discussed with the government agencies responsible for managing resources in Indonesia's peat lands especially in Sumatera, Kalimantan, and Papua islands. Currently work is in progress, with, as a first output, a draft land account for all land types being sent to various stakeholders for review.

Mexico

A1.12 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 UNSD, the UN-Environment TEEB Office and the Secretariat of the Convention on Biological Diversity (CBD), with funds provided by the Norwegian Agency for Development Cooperation (NORAD). Over the two years of implementation of the ANCA Project in Mexico, an interinstitutional 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 Mexican 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.

A1.13 In 2017 Mexico was again included as a pilot country in the EU funded project to further test ecosystem accounting together with Brazil, China, India and South Africa. Additional pilot studies will be conducted to evaluate (in physical and, whenever possible, also in monetary terms) particularly important and interesting ecosystem services either at the national-, state- or site-level.

Netherlands

A1.14 In 2016 Statistics Netherlands and Wageningen University started work on a three year project ‘Ecosystem Accounting for the Netherlands’, funded by the Dutch Ministries of Economic Affairs and Infrastructure and the Environment. The aim of this project is to test and implement SEEA EEA ecosystem accounting for the Netherlands. The choice was made to develop the core accounts and include carbon and biodiversity as thematic accounts. The focus of the set of accounts is largely on terrestrial ecosystems. A comprehensive carbon account has been released[50] and an ecosystem unit map has been compiled for the reference years 2006 and 2013.[51]

A1.15 One of the core accounts that has been developed is the biophysical ecosystem service supply and use account for the Netherlands. High-resolution spatial models

[50] https://www.cbs.nl/-/media/_pdf/2017/45/carbon-account-2017.pdf
[51] https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map

were made for a broad range of ecosystem services. Thirteen ecosystem services were modelled including five provisioning services, six regulating services and two cultural services. These ecosystem services were analysed and maps were produced. Based on the results from the spatial models, biophysical supply tables are developed and analysed. The ecosystem services supply tables were developed for ecosystem types and for the Dutch provinces. Use tables are set up for the different economic sectors that benefit from the ecosystem services. Valuation of ecosystem services and the development of ecosystem condition accounts is now under development.

Philippines[52]

A1.16 From 2014 to April 2017 the Government of the Philippines tested the SEEA EEA approach at the local levels for pilot provinces/areas in Palawan, Laguna and Quezon provinces. Pilot studies on SEEA EEA accounts were developed in two areas, in Southern Palawan and Laguna de Bay. These pilot accounts were comprised of 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 was the development of a mangroves ecosystem account specifically for the Pilot Province in Pagbilao, Quezon in Region IV-A. The mangrove account focused on: (1) area; (2) biomass; (3) carbon stock; and (4) carbon sequestration.

A1.17 The Philippine Statistics Authority (PSA) through the Environment and Natural Resources Division (ENRAD) under the Macroeconomic Accounts Service (MAS), as the country's compiler of environmental and natural resource accounts, has jointly collaborated with other government agencies in the pilot studies. For pilot studies in Palawan and Laguna provinces, these were jointly done through the Department of Environment and Natural Resources (DENR) and its various bureaus/departments such as the Forest Management Bureau, and its regional offices. The Palawan Council for Sustainable Development and the Laguna Lake Development Authority, both under the DENR, served as the lead departments on developing 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 the PSA. Various other departments provided data and supported development of the accounts. Based on the accounts, a set of 10 policy briefs on specific policy relevant topics were prepared.

Rwanda[53]

A1.18 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 Center for Ecological Analysis and Synthesis (NCEAS) at the University of California, Santa Barbara. The Rwanda ecosystem accounts are based on data between 1990 and 2015, and quantify changes in carbon storage, sediment retention and loss, and water quantity (measuring the amount of flow in rivers in the wet and dry seasons). The accounts specifically highlight the changes in water quantity, quality, and hydroelectric power generation, irrigation, and domestic water supply.

A1.19 The ecosystem accounts will inform the development of the country's third Economic Development and Poverty Reduction Strategy, scheduled to begin in August

[52] Further information in http://www.wavespartnership.org/en/philippines
[53] Further information in: http://www.wavespartnership.org/en/rwanda

2017. Furthermore, with support from WAVES and the inter-governmental Regional Centre for Mapping of Resources for Development (RCMRD), the Rwanda Natural Resources Authority developed a 2015 land cover map that allows results from ecosystem accounts to be directly compared to land use accounts (Rwanda began tracking land use in 2014). Development of the 2015 map included extensive capacity building work for the Rwanda Natural Resources Authority, and field validation of images processed from satellite data.

South Africa

A1.20 During 2014 and 2015, South Africa was one of seven pilot countries involved in the Advancing Natural Capital Accounting project (ANCA), led by the United Nations Statistics Division (UNSD) in partnership with United Nations Environment (UNEP) and the Convention on Biological Diversity (SCBD), with funding from the Government of Norway. This project enabled the development of two sets of pilot ecosystem accounts: National River Ecosystem Accounts (extent and condition of river ecosystems), and Land and Ecosystem Accounts for the province of KwaZulu-Natal. Building on these pilot accounts, South Africa is now participating as one of five countries in the EU-funded Natural Capital and Valuation of Ecosystem Services project, led by UNSD and UN Environment. The programme of work for the project is likely to include National Land and Ecosystem Accounts, and the full suite of ecosystem accounts for the province of KwaZulu-Natal. It may include other experimental accounts, for example for protected areas and species of special concern, and a National Strategy for Ecosystem Accounting will be developed.

A1.21 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 Department of Environmental Affairs that has the mandate to monitor and report on the state of the country's ecosystems. It is intended that ecosystem accounts will provide detailed spatial information on ecosystems that can inform national planning (for example, the National Spatial Development Framework) as well as municipal land-use planning, and can inform ecosystem restoration priorities.

United Kingdom

A1.22 The UK ecosystem accounts have been developed by integrating bottom-up, spatially disaggregated modelling approaches with data at a national (top-down, aggregate) level. This has enabled a time series of high level accounts for different broad habitats to be compiled in a way that is consistent and hence additive, providing 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 sub-national areas such as national parks, there has been no attempt yet to disaggregate the top-down estimates to more spatially detailed areas as research to date has shown that such dis-aggregations were not robust.

A1.23 The national level accounts already developed include a full sequence of accounts (extent, condition, service flows in physical and monetary terms, and monetary asset values) for woodlands, farmland and freshwater habitats. Initial, more exploratory accounts have been produced for marine areas, coastal margins, and for mountains/moorlands/heath. A separate ecosystem account for urban areas in the UK has also been developed, incorporating 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 main stream valuations of provisioning services, carbon sequestration and recreation.

A1.24 Although the UK accounts are still classed as experimental, they are already providing valuable insights into the way different habitats provide different services and the relative importance of these services. The results are widely referenced by the UK Government and others and their use is expected to increase as the accounts become more established.

A1.25 More details on the results and methodologies used can be found on the UK Natural Capital Accounts webpage.[54]

United States

A1.26 In late 2016, the United States Geological Survey (USGS) began coordinating with other U.S. and international agencies, academics, private industry representatives, and natural capital accounting (NCA) practitioners from other countries, to demonstrate by 2019 that natural capital accounting is feasible within the U.S.[55] Pioneering work elsewhere in development and application of the SEEA EEA, along with a relatively rich supply of national and subnational data, ecosystem services and modelling expertise, and computational resources were taken as essential elements helping to make a rapid demonstration of this type possible.

A1.27 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 U.S. Work to date has focused on land and water accounts following the SEEA Central Framework, which provide context for changes observed in the ecosystem accounts. The group aims to integrate national-scale biophysical models of ecosystem services using semantic models on the cloud. Once the initial modelling design is operational, this approach will reduce time and resources needed for all subsequent modelling runs, ensuring greater flexibility and reliability at lower cost compared to undertaking a new chain of model building and data matching for each iteration of an ecosystem account.

EU KIP INCA

A1.28 The European Union has set itself ambitious targets for the preservation and better management of natural capital in the 7th Environmental Action Programme of the EU and the EU Biodiversity Strategy to 2020. To build the knowledge base for achieving these objectives a shared Knowledge Innovation Project was set up at EU level to develop an Integrated system for Natural Capital and ecosystem services Accounting (KIP INCA). The organizations taking KIP INCA forward are Eurostat, the EU 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 EU initiative on Mapping and Assessment of Ecosystems and Services (MAES), which aims to map and assess ecosystems and their services in the EU, and supports the second phase of MAES, which aims to value ecosystem services and integrate them into accounting and reporting systems by 2020.

A1.29 The methodological starting point of KIP INCA is the UN System of Environmental-Economic Accounting- Experimental Ecosystem Accounts (SEEA EEA). The KIP INCA project aims to develop accounts on the extent and condition of ecosystems present in the European Union, as well as accounts for selected ecosystem

[54] https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/naturalcapital
[55] https://powellcenter.usgs.gov/view-project/57741607e4b07657d1a9910c

services from these ecosystems and their contribution to the economy and human well-being. The KIP INCA project began in 2015 and will run to 2020. Key results of Phase 1 of the project and a roadmap for objectives to be completed by 2020 can be found in the KIP INCA Phase 1 report[56] .

Food and Agriculture Organization of the United Nations (FAO)

A1.30 The FAO has developed the System of Environmental-Economic Accounting for Agriculture, Forestry and Fishery (SEEA-AFF), which applies the environmental economic structures and principles described in the System of Environmental Economic Accounting - Central Framework (SEEA-CF) to the activities of Agriculture, Forestry and Fisheries. The SEEA AFF has been recently implemented in Australia.[57]

A1.31 Moreover, FAO has started a collaboration with the Joint Research Centre (JRC) to develop provisioning ecosystem services accounting starting from the SEEA-AFF consistently with the System of Environmental- Economic Accounts – Experimental Ecosystem Accounts (SEEA-EEA).

A1.32 Finally, linkages and overlaps between the SEEA CF and the SEEA EEA for carbon accounting are in the scope of the collaboration in place with the Statistics Netherlands.

World Bank: WAVES program experience with ecosystem accounting

A1.33 The World Bank promotes SEEA implementation through the Wealth Accounting and the Valuation of Ecosystem Services Global Partnership (WAVES).[58] WAVES focuses on policy uptake and the institutionalization of Natural Capital Accounts (NCA) using the SEEA methodology.[59] From the WAVES standpoint the SEEA-EEA framework has been instrumental in moving towards an international statistical standard for ecosystem accounting.[60] Through WAVES, the World Bank has supported several countries in advancing efforts for ecosystem accounting (see figure below) with particular progress by the Philippines and Rwanda (see descriptions above). At the regional level, WAVES has supported communities of practice in developing ecosystem accounts, and also facilitated south-south learning. At the global level, WAVES has worked on transitioning ecosystem accounting toward an accepted international standard, making use of Earth Observation data, and better methodology for the valuation of ecosystem services.[61]

---

[56] http://ec.europa.eu/environment/nature/capital_accounting/pdf/KIP_INCA_final_report_phase-1.pdf

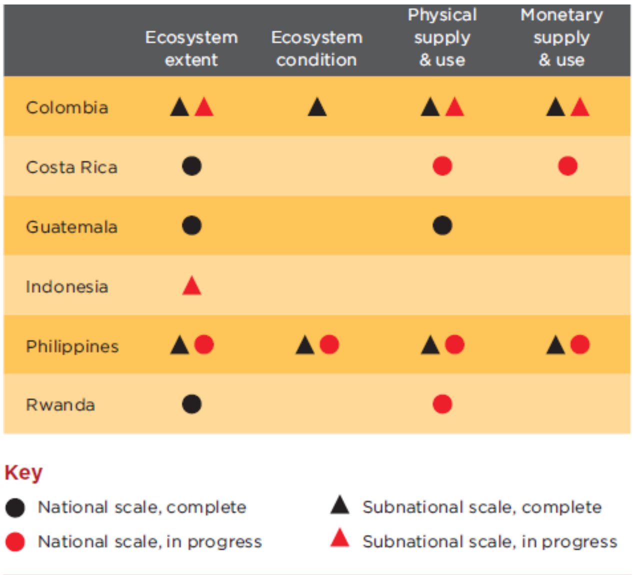
[57] http://www.abs.gov.au/ausstats/abs@.nsf/mf/4632.0.55.001

[58] Further information in: http://www.wavespartnership.org/en

[59] See for example, "Forum on Natural Capital Accounting for Better Policy Decisions: Taking Stock and Moving Forward", https://www.wavespartnership.org/en/knowledge-center/forum-natural-capital-accounting-better-policy-decisions-taking-stock-and-moving

[60] See for example, Forest Accounting Sourcebook: Policy applications and basic implementation", http://www.wavespartnership.org/en/knowledge-center/forest-accounting-sourcebook, and "Managing Coasts with Natural Solutions", https://www.wavespartnership.org/en/knowledge-center/managing-coasts-natural-solutions

[61] "Prices for ecosystem accounting", https://www.wavespartnership.org/en/knowledge-center/prices-ecosystem-accounting-draft-1 .



Source: WAVES Annual report 2017 (www.wavespartnership.org)

UNSD program and projects

A1.34 Under the auspices of the UN Committee of Experts on Environmental-Economic Accounting, the United Nations Statistics Division (UNSD) supports the methodological development of the SEEA EEA and implementation of ecosystem accounting in countries through its regular work programme and externally-funded projects including the Norwegian-funded Advancing Natural Capital Accounting (ANCA) project and the EU-funded Natural Capital Accounting and the Valuation of Ecosystem Services project

(i) Advancing Natural Capital Accounting (ANCA) project

A1.35 The ANCA project, which was jointly implemented by the United Nations Environment, UNSD, the Secretariat of the Convention on Biological Diversity and funded by the Norwegian Agency Cooperation, supported the implementation of the SEEA EEA in 7 pilot countries, namely Bhutan, Chile, Indonesia, Mauritius, Mexico, South Africa and Vietnam. The project started in December 2013 and was completed in December 2016.

A1.36 The project has developed national plans on advancing environmental-economic accounting in 7 pilot countries outlining the country plan to develop information in support of sustainable development and in advancing the SEEA implementation. The national plans detail the policy situation in the country, the institutional arrangements and legal framework for statistics, as well as the data situation. The national plans also identify on-going initiatives in the countries and highlight opportunities and risks associated with the implementation of SEEA in countries.[62]

A1.37 In additional to the national plans, the project supported the piloting two ecosystem accounts in South Africa, namely: 1) national river ecosystem accounts for South Africa and 2) land and ecosystem accounting in KwaZulu-Natal.[63] Pilot

[62] The national plans are downloadable at http://www.teebweb.org/areas-of-work/advancing-natural-capital-accounting/

[63] The two pilot reports are accessible at http://www.teebweb.org/areas-of-work/advancing-natural-capital-accounting/

ecosystem accounts were also compiled in Mexico for Aguascalientes. A range of training materials on ecosystem accounting has been developed.

(ii) Natural Capital Accounting and Valuation of Ecosystem Services project

A1.38 This project is jointly implemented by the UNSD, the United Nations Environment, 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.

A1.39 The objective of the project is to advance the knowledge agenda on environmental-economic accounting in particular ecosystem accounting, by initiating pilot testing of the SEEA Experimental Ecosystem Accounting in 5 strategic partner countries to the EU where biodiversity is at stake, namely Brazil, China, India, Mexico and South Africa, with a view to: Improving the measurement of ecosystems and their services (both in physical and monetary terms) at the (sub)national level; mainstreaming biodiversity and ecosystems in (sub)national level policy-planning and implementation; contribute to the development of internationally agreed methodology and its use in partner countries.

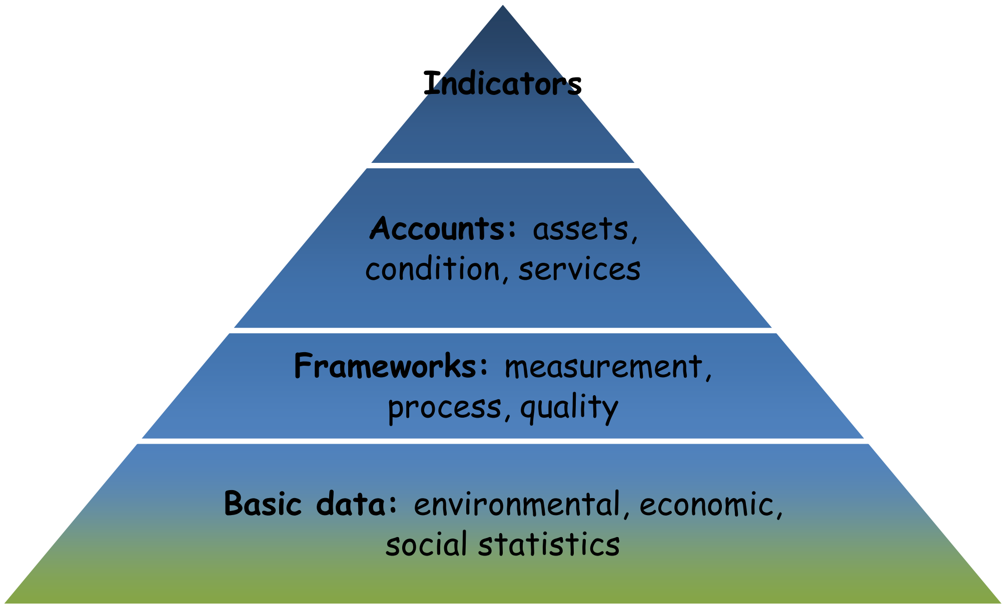
Annex 2: Key features of a national accounting approach to ecosystem measurement

Introduction

A2.1 This section explains the key features of a national accounting approach and why it provides a distinct measurement discipline that works very effectively towards the mainstreaming of environmental information into economic measures.

A2.2 To place accounting frameworks in context it is relevant to consider the information pyramid (Figure A2.1). This pyramid has as its base a full range of basic statistics and data from various sources including surveys, censuses, scientific measurement and administrative sources. Generally, these data will be collected for various purposes with the use of different measurement scopes, frequencies, definitions and classifications. Each of these data sources will be relevant to analysis or monitoring of specific themes.

Figure A2.1: Information pyramid



A2.3 The role of accounting frameworks (at the middle levels of the pyramid) is to integrate these data to provide a *single best picture* of a broader 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.

A2.4 Finally, having integrated the data within a single framework, indicators can be derived that provide insights into the changes in composition, changes in relationships between stocks and flows, and other features taking advantage of the underlying relationships in the accounts between stocks and flows, between capital and labour, between production and consumption, etc. Indicators such as GDP, national saving, national wealth, terms of trade and multi-factor productivity all emerge from the one national accounts framework.

A2.5 The following sub-sections focus on the approach that national accountants take to providing the single best picture.

Key features of a national accounting approach

A2.6 For those not familiar with the way in which national accountants work through measurement issues there are two key aspects that should be understood. First, national accounting approaches generally always commence using data from multiple sources that has already been collected. National accounting is therefore not focused on defining survey questions, determining sample sizes, collecting and processing data, etc. These important tasks are assumed to be completed by experts in specific subject matter areas, relevant methodologists and those in charge of administrative data. Ideally, there would be a close relationship between the national accounts compiler and those collecting the data but this can take time to evolve and in any event the national accountant will always remain one step removed from the source data.

A2.7 Second, in part as a result of not collecting data, but largely as a result of the underpinning conceptual framework, national accountants work "from the outside in". National accounting is not a "bottom up" measurement approach whereby aggregates are formed by summing available data. Rather, most effort goes into ensuring that the estimates that are compiled appropriately reflect the target concept, for example, economic growth or fixed capital formation or household consumption. Generally, it will be the case that no single data source can fully encapsulate a single concept and hence the role of the national accountant is to meld, integrate and otherwise combine data from multiple sources to estimate the concept as best as possible.

A2.8 Further, on this same point. It is not sufficient to obtain the best estimate of each concept in isolation. Rather the measurement of each concept must be considered in 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. Ultimately it is the ambition to produce, at a single point in time, the single best picture, of the concepts in scope of the national accounts framework. This cannot be achieved by relying on a bottom up strategy where the micro builds neatly to the macro. Instead, a top down or working from the outside in approach must be applied.

A2.9 Building on these two key aspects there are some related national accounting compilation principles that should be recognised.

i. *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. Hence changes over time must be considered 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 these time frames. Indeed, generally data sources will improve their methods and coverage over time. Consequently, a key role in national accounts is linking information from different sources and over time, and hence various methods may be applied to consistently measure the same concept.

ii. *Prices, quantities (volumes) and values are all relevant.* While the vast bulk of the national accounts framework is presented in terms of relationships in value terms (i.e. in terms of the actual monetary amounts transacted); the most significant proportion of resources on compiling national accounts are targeted at decomposing the changes in value between changes in prices or changes in underlying volumes. Generally, most analysis of the national accounts, e.g. growth rates, productivity, investment, is conducted in volume terms (i.e. after removing price effects). Again the single best picture ambition requires balancing these different perspectives at a component and aggregate level.

iii. *The 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 might be considered or new methods that might be adopted to refine the single best picture. National accounting thus works by ensuring the release at regular intervals of the best picture in the knowledge that it will be revised in due course when additional information comes to hand.

iv. *Accounting is iterative.* Fundamentally, the process of integrating data for accounting is not a single, one-off process. Each time a set of accounts is compiled different integration issues will arise and will generally only be resolved through attempting integration, understanding the reasons for imbalances, and implementing possible solutions. Gradually, a single best picture emerges. Ideally, resolving these integration issues is a task that involves both accountants and data supplying areas. Such joint resolution is an important aspect in mainstreaming different data as part of an overall picture.

A2.10 One overall consequence of a national accounting approach to compilation is that comparability between different estimates is not assessed primarily on the basis of method. In the first instance, comparability is based on the extent to which different estimates accurately reflect the target concept. Indeed, since each national accountant will be faced with the integration of different source data, a focus on comparability of methods is likely not a helpful starting point although it must be accepted that not all methods will produce estimates of equal quality.

A2.11 One benefit of a focus on concepts is that countries will tend to focus their resources on measuring those aspects within the accounting framework that are of most relevance to them. For example, in a country in which agriculture is a dominant activity, resources should be allocated to measurement of this activity. In a different economic structure, for example a country with a large finance sector, the balance of resources and the choice of data and methods will and should be different. Since economic structures changes over time, methods will also need to adapt. The development of services statistics and associated measurement methods over the past 25 years is a good example of this evolution in compilation approaches even as the underlying concepts remain stable.

Applying the national accounting approach to ecosystem accounting

A2.12 In most cases, including for the datasets that underpin ecosystem accounting, the ambition is to generate databases pertaining to a single theme or topic and to provide the best estimates based on the selected methods and resources available. While this may well and should involve comparison with other datasets as part of editing the dataset, it generally does not involve full integration and reconciliation with other datasets.

A2.13 A national accountant, on the other hand, is not compiling such a dataset but rather is seeking to undertake the integration. In many respects this is a role that must, at some point, be undertaken by a data user, analyst or decision maker. That is, at some point interpretations and judgements are needed concerning data from different sources that may suggest different trends. Within the scope of macro-economic analysis, national accountants make such judgements about relative data quality using the rigour of the national accounting framework. The alternative would be a situation where each economic analyst made their own judgements possibly using varying definitions of economic aggregates and measurement scope.

A2.14 The application of a national accounting approach within ecosystem accounting extends this national accounting compilation approach to biophysical and scientific data. That is, within ecosystem accounting the ambition is to integrate the various sources of information on ecosystem condition, ecosystem services, economic production and consumption, to present the single best picture.

A2.15 One consequence is that for ecosystem accounting it is necessary but not sufficient to have data for a particular ecosystem type or for a selected set of ecosystem services. Rather, effort must be made to obtain information that permits assessment of the whole area of interest and full scope of supply of ecosystem services. Certainly, it would be relevant to place most resources into measuring those ecosystems and their services that are considered most relevant and significant, but this should not detract from the ambition to measure the whole.

A2.16 In putting national accounts based estimates together it means that data that may be regarded as of good quality are adjusted to ensure an integrated picture. As well, since the emphasis is on the measurement of a defined framework, some data sources may not be used, whatever their quality, since they are not defined following the required concepts.

A2.17 While these statements are somewhat stark, in practice, a national accounts approach is very reluctant to ignore any information. Rather, efforts are generally made to examine all relevant data and, where necessary, make adjustments to concepts to permit integration.

A2.18 In the area of ecosystem accounting, work is ongoing to define the final integrated framework. In this context, there remains considerable scope for an active dialogue between those managing the underlying data sets and those designing the ecosystem accounting framework. This dialogue is essential for the generation of high quality information.

Principles and tools of national accounting

A2.19 The focus here is on the main principles and tools that national accountants apply to ensure coherence in the integration of data from multiple sources. The following paragraphs present a brief description of the relevant principles. An extensive discussion of the principles is contained in the SNA 2008 and an extended overview is provided in SEEA Central Framework.

A2.20 <u>Accounting identities.</u> The accounting system relies on a number of identities – that is, expressions of relationships between different variables. There are two relationships of particular importance in ecosystem accounting. First, there is the supply and use identity in which the supply of a product (or, in this case, an ecosystem service) must balance with the use of that same product. This identity applies in both physical and monetary terms. Often information on the supply and use of a product will be from multiple sources and hence this identity provides a means by which data can be reconciled.

A2.21 Second, there is the relationship between balance sheets and changes in assets. This identity is that the opening stock plus additions to stock less reductions in stock must equal the closing stock. Again, this identity applies in both physical and monetary terms. Without this identity there would be no particular reason to ensure that observed changes in ecosystem assets (e.g. through natural growth or extraction) aligned with the series of point-in-time estimates of ecosystem condition that underpin the balance sheets.

A2.22 Frequency of recording. In order to provide a single best picture across multiple data sources it is essential that there is a common reference point 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 is one year. This supports alignment with economic data that are usually compiled on this periodicity. Flows are measured such that all activity that takes place during the selected accounting period is recorded. Stocks are measured at the opening and closing dates of the accounting period.

A2.23 Commonly, different data sources will have different reference periods and thus adjustments will be required to allow appropriate integration. For example, flows may cover a date range that is not aligned with the selected accounting period and/or stock information will relate to a non-opening or closing period date. Where adjustments are made these should be made explicit or if no adjustments are made then the implicit assumptions should be described.

A2.24 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 only be detectable over periods of three to five years. In the other direction, measurement of changes in water resources may require sub-annual data to detect seasonal variation. As appropriate it is relevant to record and present specific data using these alternative frequencies such that decision making and analysis can be best supported. At the same time, a single frequency is required for the integration of all data, including economic data, and it is for this purpose that annual recording is proposed. This frequency also ensures a regular presentation of ecosystem accounting data to decision makers and supports the mainstreaming of environmental information that is a core ambition of the SEEA.

A2.25 In addition to these key principles there are a few common tools and methods that national accounts apply. These are

A2.26 Benchmarking, interpolation and extrapolation. Among the range of different data sources there will usually be a particularly high quality source in terms of coverage and quality. Commonly such a source will provide a benchmark estimate at a point in time or for a given accounting period. Using this information as a base, it is then common to use indicators to extrapolate this information to provide more up to date estimates (a process known as “nowcasting”) and also to interpolate between benchmarks, for example in cases where the best data are collected every 3 years but annual estimates are required for accounting purposes. Generally, these techniques are applied to generate the initial estimates for a particular variable and may be subsequently adjusted through the balancing and integration process.

A2.27 In some respects, these types of benchmarking and interpolation/extrapolation techniques may be regarded as a form of modelling. The extent to which this is the case will depend on the sophistication of the technique that is used. Generally, regressions and the like are not utilised since maintaining these models across the full extent of a national accounts framework would be very 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 rationalise the statistical advantage of applying detailed modelling approaches for individual series.

A2.28 Modelling. Where modelling does become more in evidence is when there is a clear shortage of data for particular variables – i.e. there are no direct estimates or benchmarks that can be used to provide a starting point. In this case, modelling may be required. An example in standard national accounts is the estimation of consumption of fixed capital (depreciation) which are commonly derived using the so-called perpetual inventory model (PIM) that requires estimates of capital formation and assumptions regarding asset lives and depreciation rates.

A2.29 In the context of ecosystem accounting, the spatial detail required is likely to considerably increase the need for modelling and this will be new ground for many national accountants. Chapter 5 of the Technical Recommendations considers the role of biophysical modelling in ecosystem accounting and the general issue of spatial imputation where information estimated in one location is applied in other locations. Such modelling and imputation may be relevant in the measurement of ecosystem extent, ecosystem condition and ecosystem services. While these may not be traditional "sources" of information for national accounts type work, there is no particular reason that such modelled data cannot be directly incorporated. It remains the task of the accountant to integrate all available data as best as possible. At the same time, a balance must be found concerning the proportion of data that are modelled within the overall dataset. Excessive reliance on modelled rather than directly collected data may raise questions about the accuracy of the information.

A2.30 A general issue that crosses all of the discussion through this section is that of data quality. Unlike many of the source data that feed into the national accounts it is not usually possible to give a precise estimate of common measures of data quality such as standard errors. The melding and synthesis of multiple data sources makes this task relatively intractable. In the same context, it is challenging to measure the significance of the application of accounting principles on data quality. While clearly these principles lead to coherence in the final data – it is often unclear how much adjustment might have been required in order for the coherence to be enforced.

A2.31 Ultimately it will often be the case that accounts are considered of a relatively good quality if the picture that they present is broadly considered a reasonably accurate one. This may emerge from consideration of

i. How well the accounts reflect and incorporate data that are considered to be of high quality.

ii. Commentary by accountants as to the extent of adjustment required (noting that in a number of situations accounts may be left unbalanced and the size of the discrepancy may be a measure of quality).

iii. The size of revisions to the estimates where a consistent pattern of large revisions to initial estimates either up or down would give an indication as to the relative quality of the source and methods.

iv. The usefulness of the data from the accounts to users. At the end of the day if the data from the accounts do not support meaningful decision making or analysis then the quality of the accounts must be questioned.

A2.32 A final area concerns the treatment of uncertainty in accounting contexts. SEEA EEA Chapter 5 provides an overview of several areas of uncertainty that may affect information used in ecosystem accounting. By its nature, accounting aims to provide a single best picture and, in this context, it would seem to ignore issues of uncertainty. Three points should be noted. First, to the extent that the inputs into an accounting exercise are subject to uncertainty then this should be taken into consideration in the compilation of the accounts themselves. Ideally, degrees of concern about the data would be the subject of description in the reporting of accounting outputs. The same holds true for any assumptions that are applied in the construction of accounting estimates – for example in terms of estimating future flows of ecosystem services in net present value calculations.

A2.33 Second, while not generally undertaken, it would be plausible to consider publishing some ecosystem accounting aggregates within sensitivity bounds. The challenge of course is to ensure that a balance in the accounting identities would be meaningfully maintained but with further consideration of how uncertainty can be usefully reflected within an accounting context would be welcome.

A2.34 Third, accounting does not provide a model for forecasting future changes in systems. The national accounts organise information about the composition and changes in economic activity but do not purport to provide future estimates of economic growth. Economic models perform this role, generally using time series of national accounts data.

A2.35 In the same way, ecosystem accounting is not designed to provide a model of how the ecosystem behaves that can be used to forecast ecological outcomes. It records, ex post, measures of changes in ecosystem condition and flows of ecosystem services. How this information might be combined to support estimates of future flows or changes in condition is a separate issue and likely subject to considerable uncertainties. This distinction between creating a structured set of information and modelling future states is often not made in scientific discourse and usually forgotten by economists. However, it is fundamental to understanding the role that accounting may be able to play in supporting the mainstreaming of environmental information into decision making.

A2.36 The inappropriateness of the national accounts as a forecasting model must be distinguished from the use of future data in the derivation of some national accounting estimates. A particular example is the use of information on future flows of services in the measurement of ecosystem capacity and ecosystem asset net present values. While it is true that net present values require information on future flows, ideally this information should be obtained from specific data sources, models and expert opinion. Where such inputs are not available, national accountants will commonly make assumptions about the future flows (usually based on past history) such that a net present value can be estimated. However, this is quite different from concluding that the national accounts framework provides a model that can be used for forecasting.

References

Arrow, K. et al. (2012) "Sustainability and the measurement of wealth", *Environmental and Development Economics*, 17: 317-353.

Ajani, J. and P. Comisari (2014) Towards a Comprehensive and Fully Integrated Stock and Flow Framework for Carbon Accounting in Australia. Australian National University, Canberra.

Atkinson G. and C. Obst (2017) *Prices for ecosystem accounting* (draft), Paper prepared as part of the work program of the World Bank WAVES project, May 2017. Available at: https://www.wavespartnership.org/en/knowledge-center/prices-ecosystem-accounting-draft-1

Australian Bureau of Statistics (2015). Information paper: An Experimental Ecosystem Account for the Great Barrier Reef Region. ABS catalogue number 4680.0.55.001, ABS, Canberra.

Bagstad, K.J., D.J. Semmens, S. Waage and R. Winthrop (2013) A comparative assessment of decision-support tools for ecosystem services quantification and valuation, *Ecosystem Services*, 5: 27–39

Bagstad, K.J., et al. (2014) From theoretical to actual ecosystem services: mapping beneficiaries and spatial flows in ecosystem services assessments, *Ecology and Society*, 19:64

Banzhaf, S. and J. Boyd (2012) The architecture and measurement of an ecosystem services index, *Sustainability* 4:430-461

Barbier, E. (2013) Wealth accounting, ecological capital and ecosystem services, *Environment and Development Economics*, 18(2):133–161

Barton D., et al. (2015) Materials and methods appendix for valuation of ecosystem services of green infrastructure in Oslo, NINA Report 1115

Bateman, I. J., G.M. Mace, C. Fezzi, G. Atkinson and K. Turner (2011) Economic analysis for ecosystem service assessment, *Environmental and Resource Economics,* 48: 177–218

Bordt (2014) Compilation of data, tools and methods, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project, United Nations.

Bordt, M. (2015a) Land and ecosystem condition and capacity, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project, United Nations.

Bordt, M. (2015b) Spatial units, scaling and aggregation, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project. United Nations.

Bordt, M. (2017) Which ecosystems provide which services? In: Bordt, M. (Ed.), Improving Convergence and Aggregation in National Ecosystem Accounting. University of Ottawa, Ottawa, Canada Doctoral Thesis. Available at: https://ruor.uottawa.ca/handle/10393/35826.

Ciais, P., M. Wattenbach, N. Vuichard, P. Smith, S. L. Piao, A. Don, S. Luyssaert, I. A. Janssens, A. Bondeau, R. Dechow, A. Leip, P. C. Smith, C. Beer, G. R. Van Der Werf, S. Gervois, K. Van Oost, E. Tomelleri, A. Freibauer and E. D. Schulze (2010) The European carbon balance. Part 2: croplands, *Global Change Biology* 16(5): 1409-1428.

Campos, P. And A. Caparrós (2011), RECAMAN PROJECT Mediterranean Monte Ecosystems Total Income Green Accounting, Presentation at the Expert Meeting on Ecosystem Accounting, May 2011, European Environment Agency, Copenhagen. (available at http://unstats.un.org/unsd/envaccounting/seearev/meetingMay2011/lod.htm

Carpenter, S.R., et al. (2010) General Resilience to Cope with Extreme Events, *Sustainability*, 4(12), 3248-3259; doi:10.3390/su4123248

Certain, G. and O. Skarpaas (2011) The Nature Index: A General Framework for Synthesizing Knowledge on the state of Biodiversity, *PLoS ONE*, 6: e18930.

CBD (1992) Convention on Biological Diversity, Article 2: Use of terms.

CBD (2003) Interlinkages between biological diversity and climate change, CBD Technical Series No 10. Secretariat of Convention on Biological Diversity, Montreal.

CBS and WUR (2015) Ecosystem Accounting Limburg Province, the Netherlands. Part I: Physical supply and condition accounts. Available at: http://www.wur.nl/en/Expertise-Services/Chair-groups/Environmental-Sciences/Environmental-Systems-Analysis-Group/Research/Ecosystem-Services-and-Biodiversity/Ecosystem-Accounting.htm

Champ, P. et al. (eds.) (2017) *A Primer on Non-market Valuation*, 2nd edition Kluwer Academic Publishing, Dordrecht.

Chapin, F.S. III, et al. (2006) Reconciling carbon-cycle concepts, terminology and methods, Ecosystems, 9:1041-1050

Cosier P. and J. McDonald (2010) A common currency for building environmental (ecosystem) accounts, Meeting of the London Group on Environmental Accounting. Santiago, 25 – 28 October 2010.

Dasgupta, P. S. (2009) The Welfare Economic Theory of Green National Accounts, *Environmental & Resource Economics*, 42(1):3–38

Day, B. (2013) An overview of valuation techniques for ecosystem accounting, School of Environmental Sciences, University of East Anglia, mimeo.

Driver, A., Sink, K.J., Nel, J.L., Holness, S.H., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. and Maze, K. (2012) National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis report. South African National Biodiversity Institute & Department of Environmental Affairs, Pretoria.

Edens, B. and L. Hein (2013) Towards a consistent approach for ecosystem accounting, *Ecological Economics*, 90:41–52

Ekins, P., et al. (2003) A framework for the practical application of the concepts of critical natural capital and strong sustainability, *Ecological Economics*, 44: 165-185

European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, World Bank (2009) System of National Accounts 2008, United Nations, New York

Eurostat and OECD (2013) Nutrient budgets: Methodology and handbook, Luxembourg.

FAO (2015) Global Forest Resources Assessment, 2015: How are the World's Forests Changing? Rome. Available at: http://www.fao.org/3/a-i4793e.pdf

FAO and United Nations (2016) SEEA Agriculture, Forestry and Fisheries, Draft presented to the 11th meeting of UNCEEA, 22-24 June, 2016.

FAO and Global Land Cover Network (2009) Land Cover Classification System v.3 (or Land Cover Meta Language): Design criteria. Rome.

Farley, J, (2008) Valuing Natural Capital: The Limits of Complex Valuation in Complex Systems, Conference Paper – Economics and Conservation in the Tropics: A Strategic Dialogue, Jan 31 – Feb 1, 2008. Available from: http://www.rff.org/files/sharepoint/Documents/08_Tropics_Conference/Tropics_Conference_Farley_Valuing%20Natural%20Capital.pdf

Fenichel, E.P. and J.K. Abbott (2014) Natural capital: From Metaphor to measurement, *Journal of the Association of Environmental and Resource Economists*, 1(1): 1-27.

Freeman, A.M. III, et al. (2013) *The Measurement of Environmental and Resource Values: Theory and Methods*, 3rd edition, RFF Press, Washington DC.

Haines-Young R. and M. Potschin (2013) Common International Classification of Ecosystem Services (CICES), Consultation on version 4, August-December 2012, EEA Framework Contract No EEA/IEA/09/003

Hamilton, K. and M. Clemens (1999) Genuine savings rates in developing countries, World Bank Economic Review, Vol 13 (2): 333-356

Harrison, A. (1993) The Draft Handbook and the UNSTAT Framework: Comments. In: Lutz E (ed) Toward Improved Accounting for the Environment. World Bank, Washington D.C.

Hein, L. (2014) Guidelines for biophysical modelling and mapping, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project, United Nations.

Hein, L., et al. (2015) Progress and challenges in the development of ecosystem accounting as a tool to analyse ecosystem capital, *Current Opinion in Environmental Sustainability*, 14: 86-92

Hein, L., et al. (2016) Defining ecosystem assets for natural capital accounting, *PLOS One*, 11(11): e0164460, doi:10.1371/journal. pone.0164460

International Integrated Reporting Council (2013), "The international framework", IIRC, available at: www.theiirc.org

IUCN (2014) The IUCN Red List of Threatened Species. Version 2014.1. http://www.iucnredlist.org.

Ivanov, E. (2015) Land accounts and ecosystem extent, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project, United Nations.

Karl, J.W. (2010) Spatial Predictions of Cover Attributes of Rangeland Ecosystems Using Regression Kriging and Remote Sensing, *Rangeland Ecology & Management*, 63, Issue 3, May 2010, Pages 335–349

Keith, D.A., Rodríguez, J.P., Rodríguez-Clark, K.M., Nicholson, E., Aapala, K., Alonso, A., Bachman, S., Basset, A., Barrow, E.G., Benson, J.S., Bishop, M.J., Bonifacio, R., Brooks, T.M., Burgman, M.A., Comer, P., Comín, F.A., Essl, F., Faber-Langendoen, D., Fairweather, P.G., Holdaway, R.J., Jennings, M., Kingsford, R.T., Lester, R.E., Mac Nally, R., McCarthy, M.A., Moat, J., Oliveira-Miranda, M.A., Pisanu, P., Poulin, B., Regan, T..J., Riecken, U., Spalding, M.D. and Zambrano-Martinez, A. (2013) Scientific foundations for an IUCN Red List of ecosystems. *PLoS ONE,* 8(5): e62111.

La Notte, A., J. Maes, S. Dalmazzone, N. Crossman, B. Grizzetti, G. Bidoglio (2017) Physical and monetary ecosystem service accounts for Europe: A case study for in-stream nitrogen retention, Ecosystem Services, 23:18-29

La Notte, A., S. Vallecillo, C. Polce, G. Zulian, J. Maes (2017) Implementing an EU system of accounting for ecosystems and their services: Initial proposals for the implementation of ecosystem services accounts, EUR28681 EN ; Publications Office of the European Union, Luxembourg, doi :10.2760/214137, JRC107150

Landers, D. H. and A.M. Nahlik (2013) Final ecosystem goods and services – Classification system. US Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Maes, J., A. Teller, M. Erhard, C. Liquete, L. Braat, P. Berry and G. Bidoglio (2013), Mapping and Assessment of Ecosystems and their Services, An Analytical Framework for Ecosystem Assessments under Action 5 of the EU Biodiversity Strategy to 2020, Publications Office of the European Union, Luxembourg.

Maynard, S., D. James and A. Davidson (2014) Determining the value of multiple ecosystem services in terms of community wellbeing: Who should be the valuing agent? *Ecological Economics*

Millennium Ecosystem Assessment (2005) Volume I. Ecosystems and human well-being: Current state and trends. Island Press, Washington, D.C.

Nel, J.L. and A. Driver (2015) National River Ecosystem Accounts for South Africa. Discussion document for Advancing SEEA Experimental Ecosystem Accounting Project, October 2015. South African National Biodiversity Institute, Pretoria

Nordhaus, W.D. (2006) "Principles of national accounting for nonmarket accounts", in Jorgenson, D. et al. (eds.) *A New Architecture for the US National Accounts*, Chicago University Press, Chicago.

Obst, C. and M. Vardon (2014) Recording environmental assets in the national accounts, *Oxford Review of Economic Policy*, Vol 30, 126-144.

Obst C., L. Hein, B. Edens (2015). National accounting and the valuation of ecosystem assets and their services. *Environmental and Resource Economics*, DOI 10.1007/s10640-015-9921-1

OECD (2009) Measuring Capital: OECD Manual, second edition, OECD, Paris.

OECD, IMF, ILO, Interstate Statistical Committee of the CIS (2002) Measuring the non-observed economy: A handbook, OECD, Paris.

Pascual U., et al. (2017) Valuing nature's contributions to people: the IPBES approach, Current Opinion in Environmental Sustainability, 26: 7-16

Philips, S. J., R.P. Anderson and R.E. Schepire (2006) Maximum entropy modelling of species geographic distributions, *Ecological modelling*, 190: 231-259

Plummer, M. L. (2009) Assessing benefit transfer for the valuation of ecosystem services, *Frontiers in Ecology and the Environment*, 7: 38–45. doi:10.1890/080091

Potter, C. S. (1993) Terrestrial ecosystem production: a process model based on global satellite and surface data, *Global Biogeochemical Cycles*, 7(4): 811-841

Remme, R. P., M. Schröter and L. Hein (2014) Developing spatial biophysical accounting for multiple ecosystem services, *Ecosystem Services*, 10, 6-18

Remme, R.P., B. Edens, M. Schröter and L. Hein (2015) Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. *Ecological Economics*, 112: 116-128.

Remme, R. P., L Hein and C. van Swaay (2016) Exploring spatial indicators for biodiversity, *Ecological Indicators*, 70, pp 232–248

Running, S. W., R. R. Nemani, F. A. Heinsch, M. Zhao, M. Reeves and H. Hashimoto (2004) A continuous satellite-derived measure of global terrestrial primary production, *BioScience*, 54(6): 547-560.

Sbrocchi C., et al. (2015) *Evaluation of the Australian Regional Environmental Accounts Trial*, Wentworth Group of Concerned Scientists, Sydney

Schröter, M., D.N. Barton, R.P. Remme and L. Hein (2014) Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway, *Ecological Indicators*, 36:539-551

Schröter M., et al. (2015) Lessons learned for spatial modelling of ecosystem services in support of ecosystem accounting, *Ecosystem Services*, 13: 64–69

Statistics Canada (2010) Freshwater Supply and Demand in Canada, Human Activity and the Environment, 16-201-X. Ottawa: Government of Canada.

Statistics Canada (2013) Measuring Ecosystem Goods and Services 2013, Human Activity and the Environment, 16-201-XWE. Ottawa: Government of Canada.

Statistics Canada (2016) The changing landscape of Canadian metropolitan areas, Human Activity and the Environment. 16-201-X. Ottawa: Government of Canada.

Stoorvogel, Jetse J., Michel Bakkenes, Arnaud J. A. M. Temme, Niels H. Batjes and Ben ten Brink (2016) S-World: a Global Soil Map for Environmental Modelling, *Land Degradation and Development*, doi: 10.1002/ldr.2656.

Sumarga E. and L. Hein (2014) Mapping ecosystem services for landscape planning, the case of Central Kalimantan, *Environmental management*, 54: 84-97.

Sumarga E., et al. (2015) Mapping monetary values of ecosystem services in support of developing ecosystem accounts, *Ecosystem Services*, 12: 71–83.

TEEB (2010a) The economics of ecosystems and biodiversity, Mainstreaming the economics of nature. A synthesis of the approach, conclusions and recommendations of TEEB. Routledge, Oxford, UK.

TEEB (2010b) The economics of valuing ecosystem services and biodiversity (Chapter 5). Available at: http://www.teebweb.org/wp-content/uploads/2013/04/D0-Chapter-5-The-economics-of-valuing-ecosystem-services-and-biodiversity.pdf

Turner, D. P., W. D. Ritts, Z. Yang, R. E. Kennedy, W. B. Cohen, M. V. Duane, P. E. Thornton and B. E. Law (2011) Decadal trends in net ecosystem production and net ecosystem carbon balance for a regional socioecological system *Forest Ecology and Management*, 262(7): 1318-1325.

UK National Ecosystem Assessment (2011) The UK National Ecosystem Assessment: Synthesis of the key findings. UNEP-WCMC, Cambridge.

UK ONS (2016) Scoping UK Coastal Margin Ecosystem Accounts, Office for National Statistics, London. Available from: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/scopingukcoastalmarginecosystemaccounts

UK ONS (2017) Principles of Natural Capital Accounting, Office for National Statistics, London. Available from: https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/principlesofnaturalcapitalaccounting

United Nations (1993) Handbook of National Accounting: Integrated Environmental and Economic Accounting, Interim version. Studies in methods, Series F, No. 61. United Nations, New York.

United Nations (2012a) International Recommendations for Water Statistics. Statistical Papers, Series M, No.91. Sales No. 10.XVII.15.

United Nations (2012b) SEEA-Water: System of Environmental-Economic Accounting for Water. Statistical Papers, Series F, No.100. Sales No. E11.XVII.12.

United Nations (2015) Framework for the Development of Environment Statistics, New York.

United Nations Statistics Division (2013) System of environmental-economic accounting 2012 – Implementation guide, Draft presented to the London Expert Group on Environmental-Economic Accounting, November 2013.

United Nations, World Tourism Organisation, European Commission and OECD (2010). Tourism Satellite Account: Recommended Methodological Framework 2008, Studies in Methods Series F No 80/ rev1. United Nations, New York.

United Nations, European Commission, Food and Agricultural Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, The World Bank (2014a) System of Environmental-Economic Accounting 2012 – Central Framework. United Nations, New York

United Nations, European Commission, Food and Agricultural Organization of the United Nations, Organisation for Economic Co-operation and Development, The World Bank (2014b) System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting. United Nations, New York

United Nations, European Union, Food and Agricultural Organization of the United Nations, Organisation for Economic Co-operation and Development, The World Bank (2017) System of Environmental-Economic Accounting 2012 – Applications and Extensions. United Nations, New York.

UNDP (2014) Human Development Report. UNDP, New York.

UNEP (2015) Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States, UNEP, Nairobi.

UNEP-WCMC (2015) Experimental Biodiversity Accounting as a component of the System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA). Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project. United Nations. Available from: http://wcmc.io/SEEA_EEA_Bio_Accounting

UNEP-WCMC (2016) Exploring approaches for constructing Species Accounts in the context of the SEEA EEA. Available at: http://wcmc.io/Species_Accounting

UNU-IHDP and UNEP (2014) Inclusive Wealth Report, 2014, Measuring Progress Toward Sustainability. Cambridge University Press, Cambridge, UK

UNWTO (2017) Statistical Framework for Measuring Sustainable Tourism, Preliminary draft prepared for the 6th International Conference on Tourism Statistics, Manila, Philippines, June 2016. Available from: https://custom.cvent.com/E5C28A0D212A415D9AD3C8B699EBC072/files/121578cbeb154e25a9f124813a3e754e.pdf

United States Environmental Protection Agency (US EPA) (2015) *National Ecosystem Services Classification System (NESCS): Framework design and policy application*. EPA-800-R-15-002, Washington DC, USEPA.

Vanoli, A. (1995) Reflections on Environmental Accounting Issues, *Review of Income and Wealth*, 41(2):113-137

Vardon, M. (2014a) Water and ecosystem accounting, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project, United Nations.

Vardon, M. (2014b) Carbon and ecosystem accounting, Supporting document to the Advancing the SEEA Experimental Ecosystem Accounting project. United Nations.

Victorian Department of Sustainability and Environment (2013) Victorian experimental ecosystem accounts, Victorian Government, East Melbourne, Australia.

WAVES-Philippines (2016) Pilot Ecosystem Account for Southern Palawan, WAVES Technical Report, November, 2016. Available from: https://www.wavespartnership.org/sites/waves/files/kc/WB_Southern%20Palawan%20Tech%20Report_FINAL_Nov%202016.pdf

Weber, J-L. (2011) An experimental framework for ecosystem capital accounting in Europe, EEA Technical Report No 13/2011, ISSN 1725-2237, European Environment Agency, Copenhagen, Denmark.

Weber, J-L (2011) Recording ecological debts in the national accounts. Research paper Available from: https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=14&ved=0ahUKEwjv9o32hrPWAhUDNJQKHUVCAqsQFghnMA0&url=http%3A%2F%2Fprojects.eionet.europa.eu%2Fleac%2Flibrary%2Fcube%2Frecording_ecological%2Fdownload%2Fen%2F1%2FRecording%2520ecological%2520debts%2520in%2520the%2520national%2520accounts_edited.doc&usg=AFQjCNFO2nC1JXcZpuIHobZWkdhEzcQRIg

Weber, J-L. (2014a) Ecosystem Natural Capital Accounts: A Quick Start Package, Technical series No. 77. Secretariat of the CBD. Montreal

Weber, J-L. (2014b) Mauritius case study of experimental ecosystem natural capital accounts: Methodology and preliminary results. Indian Ocean Commission, Mauritius.

Willemen, L., et al. (2015) Best Practices for Mapping Ecosystem Services, *Ecosystem Services*, Volume 13: 1–5

World Bank (2011) The Changing Wealth of Nations, World Bank, Washington D.C.

World Bank (2014) Designing Pilots for Ecosystem Accounting, WAVES, World Bank, Washington.

World Bank (2017) Better Policy through Natural Capital Accounting: Stocktaking and Ways Forward, 7th WAVES Annual Partnership Meeting Edition, June 2017. Available from: https://www.wavespartnership.org/sites/waves/files/kc/Policy%20forum%20papers%20%281%29.pdf

World Wildlife Fund (2014) Living Planet Report. WWF/ESA.